RADIOISOTOPES AT WORK FOR AGRICULTURE

Prepared for:
OFFICE OF ISOTOPE DEVELOPMENT
UNITED STATES ATOMIC ENERGY COMMISSION WASHINGTON, D.C.

USAEC Contract No. AT(04-3)-115
Project No. II

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA
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RADIOISOTOPES AT WORK FOR AGRICULTURE

By: A. Gerlof Homan and Richard R. Tarrice

SRI Project No. IU-2814

Prepared for:
OFFICE OF ISOTOPE DEVELOPMENT
UNITED STATES ATOMIC ENERGY COMMISSION WASHINGTON, D.C.

USAEC Contract No. AT(04-3)-115
Project No. 11

Approved:

Charles L. Hamman
ASSISTANT DIRECTOR OF ECONOMICS RESEARCH

Paul J. Lovewell
DIRECTOR OF ECONOMICS RESEARCH
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>3</td>
</tr>
<tr>
<td>III</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>17</td>
</tr>
<tr>
<td>V</td>
<td>27</td>
</tr>
<tr>
<td>VI</td>
<td>39</td>
</tr>
</tbody>
</table>

I INTRODUCTION ........................................... 1

II SUMMARY AND CONCLUSIONS .............................. 3

III RESEARCH AND INCREASING AGRICULTURAL PRODUCTIVITY 5

- Role of Research ...................................... 5
- Growth in Productivity ................................ 6
- Savings from Increased Productivity ................. 15

IV BENEFITS FROM THE AVAILABILITY AND USE OF RADIOISOTOPES 17

- Research Using Radioisotopes in Perspective ......... 17
- Benefits from Selected Projects ...................... 18
- Evaluation of Benefits from Radioisotope Use .......... 25

V ANALYSIS OF RADIOISOTOPE USE AT EXPERIMENT STATIONS AND OTHER ORGANIZATIONS 27

- Agricultural Experiment Stations .................... 27
- Survey of Other Organizations ....................... 33

VI CURRENT AND POSSIBLE FUTURE APPLICATIONS OF RADIOISOTOPES IN AGRICULTURAL RESEARCH 39

- Farm Animal Sciences and Veterinary Medicine ....... 39
- Agricultural Entomology ................................ 42
- Plant Genetics ......................................... 44
- Plant Physiology ....................................... 46
- Soil Sciences and Water ................................ 47
Table of Contents (Continued)

<table>
<thead>
<tr>
<th>Appendix</th>
<th>CONSULTANTS' REPORTS ON CURRENT AND POSSIBLE FUTURE APPLICATIONS OF RADIOISOTOPES</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>RADIOISOTOPES AND THE LIVESTOCK INDUSTRY, C. L. Comar, F. W. Lengemann, R. H. Wasserman, New York State Veterinary College, Cornell University, Ithaca, New York</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>USES OF RADIOISOTOPES IN AGRICULTURAL ENTOMOLOGY, W. M. Hoskins, Department of Entomology and Parasitology, University of California, Berkeley, California</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>A TECHNICAL REPORT ON ISOTOPES IN AGRICULTURE--GENETICS, C. F. Konzak, Associate Professor of Agronomy and Associate Agronomist, State College of Washington, Pullman, Washington</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>RADIOISOTOPE APPLICATIONS IN THE STUDY OF PLANT PHYSIOLOGY, H. B. Tukey and J. N. Buchovac, Michigan State University, East Lansing, Michigan</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>INVESTIGATIONS OF SULPHUR ON PLANT-SOIL RELATIONSHIPS, S. C. Fang and M. E. Harward, Oregon State College, Corvallis, Oregon</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>RADIOISOTOPES IN AGRICULTURE: SOIL AND WATER, H. M. Benedict, Director of the Agricultural Research Center, Stanford Research Institute, Menlo Park, California</td>
<td>141</td>
</tr>
<tr>
<td>B</td>
<td>TABULATION OF DATA FROM QUESTIONNAIRES</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>AGRICULTURAL EXPERIMENT STATION RESEARCH PROJECTS USING RADIOISOTOPES</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>SURVEY OF OTHER ORGANIZATIONS USING RADIOISOTOPES IN AGRICULTURAL RESEARCH</td>
<td>196</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Trends in Farm Input and Production</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Dollars of Farm Output per Unit of Input</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>Trends in Yields of Selected Farm Products</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Trends in Yields of Selected Farm Products</td>
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LIST OF TABLES

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Farm Output per Unit of Labor, Land, and Capital Input</td>
<td>8</td>
</tr>
<tr>
<td>II</td>
<td>Sources of Change in Farm Output, United States</td>
<td>10</td>
</tr>
<tr>
<td>III</td>
<td>Trends in Yields of Selected Farm Commodities</td>
<td>12</td>
</tr>
<tr>
<td>IV</td>
<td>United States Farm Production Index and Agricultural Research Expen</td>
<td>19</td>
</tr>
<tr>
<td>V</td>
<td>Estimated Losses to Agricultural Production from Various Hazards</td>
<td>20</td>
</tr>
<tr>
<td>VI</td>
<td>Major Radioisotopes Used by the Reporting Experiment Stations</td>
<td>29</td>
</tr>
<tr>
<td>VII</td>
<td>Fields of Agricultural Research at Reporting Experiment Stations</td>
<td>31</td>
</tr>
<tr>
<td>VIII</td>
<td>Size and Number of Research Programs Involving Radioisotopes at 36</td>
<td>34</td>
</tr>
<tr>
<td>IX</td>
<td>Number of Other Organizations and Their Projects Using Radioiso</td>
<td>36</td>
</tr>
<tr>
<td>X</td>
<td>Some Possible Future Uses of Radioisotopes in Animal Sciences and</td>
<td>41</td>
</tr>
<tr>
<td>XI</td>
<td>Possible Economic Benefits of Radioisotopes to the Livestock Industry</td>
<td>43</td>
</tr>
<tr>
<td>A-1</td>
<td>Mutations Induced</td>
<td>117</td>
</tr>
<tr>
<td>B-1</td>
<td>Survey of 12 Agricultural Journals</td>
<td>200</td>
</tr>
</tbody>
</table>
Section I
INTRODUCTION

The Office of Isotopes Development of the United States Atomic Energy Commission has requested that Stanford Research Institute prepare a report on the applications of radioisotopes in agriculture. This report is to provide one of several bases for appraisal of the radioisotope program. The work was done under Contract Number AT (04-3)-115, Project Agreement 11.

The objectives of this report are to estimate the probable economic benefits from the use of radioisotopes in agriculture at present and in the future, and to present a detailed analysis of the current and probable future uses for radioisotopes in agriculture.

Because the use of radioisotopes in agriculture is only beginning, the limits of its economic benefits are difficult to define. In order to make an estimate, an economic framework was developed to give perspective to the use of radioisotopes in agriculture.

Data on the current and probable future uses for radioisotopes in agriculture were collected by interviews and questionnaires. The following institutions were visited:

Cornell University, Ithaca, New York
University of California, Berkeley, California
University of California, Davis, California
University of California, Riverside, California
University of California, Los Angeles, California
Michigan State University, East Lansing, Michigan
Oklahoma State University, Stillwater, Oklahoma
Oregon State College, Corvallis, Oregon
Texas A & Am College, College Station, Texas
Brookhaven National Laboratory, Brookhaven, New York
Questionnaires were sent to agricultural experiment stations at land-grant colleges and other organizations.

Technical studies on current and probable future uses of radioisotopes in agricultural research were furnished the Institute by consultants in the major fields of agricultural research. The following scientists served as consultants:

- C. L. Comar, R. H. Wasserman, F. W. Lengemann
  Cornell University
  Animal Physiology, Veterinary Medicine

- H. B. Tukey, J. N. Buchovac
  Michigan State University
  Plant Physiology

- W. M. Hoskins
  University of California (Berkeley)
  Entomology

- C. F. Konzak
  Washington State College
  Plant Genetics

- S. C. Fang, M. E. Harward
  Oregon State College
  Fertilizer Studies

- H. M Benedict
  Stanford Research Institute
  Soil and Water

Research was conducted by A. Gerlof Homan, project leader in collaboration with Richard R. Tarrice, project manager. Dr. Michael Nelson assisted in the preparation and analysis of the basic economic data. Betty J. Maynard and Suzanne L. Perez assisted in the handling of the technical details of the survey and data collection. Special editorial and analytical assistance was provided by Mary Lou Wynne. This study was carried out in the Resource Development Department of the Division of Economics Research under the administrative supervision of Charles L. Hamman, Assistant Director of the Division.
Radioisotopes are a relatively new research tool whose greatest contribution to agriculture is in their making it possible to obtain knowledge from research with more ease and accuracy and to obtain new knowledge that could not be obtained in any other known way. Knowledge obtained from agricultural research has made it possible to increase the rate of productivity in the agricultural industry.

Based on the total savings to the industry from increasing productivity from 1957 to 1980 and the ratio of expenditures in fiscal year 1958-59 for total agricultural research and agricultural research using radioisotopes, a minimum estimated savings of $180 million a year for the next 20 years can be attributed to the use of radioisotopes in agricultural research.

The use of radioisotopes in agricultural research at present is primarily in investigations directed to the reduction of losses, due to diseases, insects, and weeds, that total approximately $11 billion a year. One aim of agricultural research is to learn to control and eventually eliminate such losses. Another aim of agricultural research is to continue to increase productivity through a better understanding of life's processes—for example, optimal levels of feeding or controlled breeding.

The extent of the use of radioisotopes in agricultural research cannot be appreciated by adding a total of the number of research projects using radioisotopes. The relative importance of the individual projects and the extent of their application of radioisotopes vary a great deal. The application of radioisotopes varies not only with the development of radioisotope methodology, largely dependent upon the critical problems at individual research centers and the availability of trained personnel and funds, but also with the availability of specific radioisotopes. The

radioisotopes used most often are those with a comparatively long half-life; research centers nearest to the reactors are the most frequent users of radioisotopes with a comparatively short half-life.

The SRI-estimated savings of $180 million a year from the use of radioisotopes in agricultural research is a minimum figure. Because the use of radioisotopes in agricultural research has only begun, there is no past experience upon which future projections can be based. The few direct economic benefits from the use of radioisotopes in research that have been recognized may increase at a slow, steady, and effective rate, or they may react on each other, producing new benefits at a dramatic rate.

It seems more than reasonable to assume that the volume of radioisotopes used in agricultural research will double in the next 10 years, that their application will follow the present patterns, and that their use will continue to contribute to an increasing rate of productivity through research.
Section III
RESEARCH AND INCREASING AGRICULTURAL PRODUCTIVITY

Because radioisotopes are a relatively new tool that has only recently been used for experimental work in agricultural research, its benefits have just begun to be realized. Measure of the agricultural benefits derived from research is reliable only when made over an extended period of time. This extended period is necessary because there is a lag between the time sufficient new agricultural knowledge is gathered to develop a new product or a new technique and the time it is produced commercially or adapted for use by farm operators. The time between the first expenditure for research and the final useful results may vary over a wide range. This time lag makes it necessary to evaluate the benefits from the relatively new use of radioisotopes in agricultural research within the framework of benefits of agricultural research in general.

The U.S. government has been the major source of funds to support scientific research for the agricultural industry. In addition, state governments, private research organizations, and industries manufacturing farm supplies--such as fertilizer, insecticides, and feeds--have made significant contributions. Since evaluation of private investments for agricultural research would involve more extensive studies than the scope of this project will allow, the analysis which follows is almost entirely based on government and directly related expenditures.

Role of Research

Our rapidly increasing population could not have a rising standard of living without increased productivity which is largely the result of efforts by well-organized groups who systematically delve into all phases of an industry to raise its level of technology. This work is called research. Although the level of technology of an industry is also significantly affected by innovations developed in operations, there is a definite relationship between research expenditures and an increase in productivity.

Increasing productivity in agriculture is important for a number of reasons. The most important is that in the future there are going to be more people to feed. World population is expected to double in less than
50 years. The population of North America is expected to increase by 43 percent from 1950 to 1975.1/ This means that in order to maintain the current domestic standard of living, agricultural production must increase by 43 percent; and if our standard of living continues to rise, agricultural production must increase by more than 43 percent. It is expected that this increased demand for agricultural production will be met primarily by increased productivity through research.

The returns realized on the present rate of expenditures to develop new techniques and to induce farm operators to adopt them are large. Rapidly rising farm wages resulting in part from improved job opportunities outside agriculture paved the way for mechanization which, in turn, contributed to an increase in the size of farms. The production of better quality products at relatively low unit cost is first introduced for additional profit. When the industry as a whole has adopted the new methods that produce these advantages, the benefits of reduced unit cost of production are passed on to the consumer. Through this process the country benefits from increasing productivity in agriculture—benefits which are passed on to the consumer more rapidly than in most other industries.

Farm operators also adapt new techniques because of institutional economic factors, such as high guaranteed farm prices and acreage restrictions.

Growth in Productivity

It is through the general process of rising productivity in agriculture that the economic benefits from research can be assessed. Thus it is necessary to study the agricultural industry's output and production problems in the same way one would proceed to evaluate the effects of automation on the automobile or chemical industry.

In response to the rapid growth in demand for agricultural products, the rate of increased productivity has been marked. Technological developments in agriculture have progressed at a remarkable rate for the last 25 years. These developments have radically changed production methods and increased operating efficiency. They have resulted in farm

1/ The Future Growth of World Population, United Nation's Department of Economic and Social Affairs, New York, 1958.
commodities being produced with less productive resources per unit, more output per unit of input, or increased productivity.

Farm production, that is, output from land, labor, and capital inputs, from 1925 to 1957 is shown in Table I and Figure 1. Total farm output increased by 62 percent. Capital input increased by 60 percent, but land input remained about the same, and labor input decreased by about 42 percent. This rapid increase in farm production is a measure of an advancing technology derived largely from research.

The relative value of the factors which have been responsible for increased farm production are shown in Table II. It should be noted that the intensification of land use from fertilizer and better plants and improved livestock from better breeding, feeding, and disease control were the most important factors. Technology in these areas has advanced largely through the efforts of research in plant, soil, and animal sciences. Research benefits can be evaluated best in terms of output per unit of input.

The effect of a rising productivity can be measured by the savings or relative decline in inputs as output rises. This relationship is shown in Figure 2. The theory can be illustrated as follows: If in the year 1900 about 100 units of inputs, including land, labor, capital, and management, were required to produce 1,000 units of farm products, then an average input of 1 unit would produce 10 units of output. If in 1950 about 200 units of inputs were required to produce 4,000 units of outputs, then an average input of 1 unit would produce 20 units of output. The efficiency of the inputs can be said to have increased twofold because in 1950 a doubling of inputs produced 4 times the 1900 output. Thus, the efficiency of the inputs increased 100 percent over a 50-year period—productivity in the industry increased at an average of 1.4 percent per year.

Table III and Figures 3 and 4 show the effect of increased productivity on the trend of yields for selected farm commodities from 1925 to 1958.

Between 1910 and 1950, the inputs in agriculture increased by an estimated 14 percent1/ while production increased by 74 percent—an average improvement in productivity of 1.35 percent per year. The rate of

Table I

FARM OUTPUT PER UNIT OF LABOR, LAND, AND CAPITAL INPUT
1925–1957

<table>
<thead>
<tr>
<th>Year</th>
<th>Farm Production Output (millions of dollars)</th>
<th>Farm Workers, Labor Input (thousands of workers)</th>
<th>Output per Labor Input</th>
<th>Farm Acreage Land Input (thousands of acres)</th>
<th>Output per Land Input</th>
<th>Current Farm Expenditures Capital Input (millions of dollars)</th>
<th>Output per Capital Input</th>
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<td>$24,617</td>
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<td>1955</td>
<td>39,564</td>
<td>8,364</td>
<td>4,730</td>
<td>332,870</td>
<td>114.7</td>
<td>19,782</td>
<td>2.00</td>
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<tr>
<td>1956</td>
<td>40,161</td>
<td>7,820</td>
<td>5,136</td>
<td>332,870</td>
<td>114.7</td>
<td>19,991</td>
<td>2.01</td>
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<td>1957</td>
<td>39,873</td>
<td>7,577</td>
<td>5,275</td>
<td>332,870</td>
<td>114.7</td>
<td>20,185</td>
<td>1.98</td>
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</tbody>
</table>

Notes: All dollar values in 1947 constant dollars.
Farm output equals total gross farm income including government payments, marketings, and nonmoney income.
Capital input equals current operating expenses excluding hired labor, farm capital expenditures, property taxes and farm mortgage interest, net rent to nonfarm landlords.

NOTE: All dollars are in 1947 Constant Dollars.

\(^1\) Capital input is current operating expenses as noted in Table I

SOURCE: See Table I

FIGURE 1
TRENDS IN FARM INPUT AND PRODUCTION
1925-1957

9
Table II

SOURCES OF CHANGE IN FARM OUTPUT, UNITED STATES
Specified Periods, 1919-55

<table>
<thead>
<tr>
<th>Sources of Change</th>
<th>Interwar 1919-21 to 1938-40</th>
<th>World War II and Postwar 1940-41 to 1955</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Index Points</td>
<td>Index Points</td>
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<tr>
<td></td>
<td>Per Year(^1/^)</td>
<td>Percent of Total</td>
</tr>
<tr>
<td>Reduction of Farm-Produced Power (such as horsepower)</td>
<td>0.39</td>
<td>51</td>
</tr>
<tr>
<td>Change in Crop Production per Acre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shifts in crop acreage</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>Weather</td>
<td>-0.12</td>
<td>-15</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>0.08</td>
<td>10</td>
</tr>
<tr>
<td>Hybrid corn</td>
<td>0.05</td>
<td>7</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>0.24</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>0.26</td>
<td>34</td>
</tr>
<tr>
<td>Change in Cropland Used</td>
<td>-0.03</td>
<td>-4</td>
</tr>
<tr>
<td>Change in Productive Output of Livestock</td>
<td>0.12</td>
<td>15</td>
</tr>
<tr>
<td>Change in Pasture Consumed by Livestock</td>
<td>0.03</td>
<td>4</td>
</tr>
<tr>
<td>Average Annual Change</td>
<td>0.77</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^1/^\) Changes are measured in output index points, with the average of the years 1947-49 taken as a base period, or 100 points. This provides a measure of absolute change.

FIGURE 2

DOLLARS OF FARM OUTPUT PER UNIT OF INPUT
(in 1947 Dollars)
1925-1957

SOURCE: See Table I
Table III

TRENDS IN YIELDS OF SELECTED FARM COMMODITIES
1925-1958

<table>
<thead>
<tr>
<th>Year</th>
<th>Production per Harvested Acre</th>
<th>Production per Milk Cow</th>
<th>Production per Animal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cotton (pounds)</td>
<td>Wheat (bushels)</td>
<td>Soybeans (bushels)</td>
</tr>
<tr>
<td>1925</td>
<td>173.5</td>
<td>12.8</td>
<td>11.7</td>
</tr>
<tr>
<td>1926</td>
<td>192.9</td>
<td>14.7</td>
<td>11.2</td>
</tr>
<tr>
<td>1927</td>
<td>161.7</td>
<td>14.7</td>
<td>12.2</td>
</tr>
<tr>
<td>1928</td>
<td>163.3</td>
<td>15.4</td>
<td>13.6</td>
</tr>
<tr>
<td>1929</td>
<td>164.2</td>
<td>13.0</td>
<td>13.3</td>
</tr>
<tr>
<td>1930</td>
<td>158.1</td>
<td>14.2</td>
<td>13.0</td>
</tr>
<tr>
<td>1931</td>
<td>211.5</td>
<td>16.3</td>
<td>15.1</td>
</tr>
<tr>
<td>1932</td>
<td>173.5</td>
<td>13.1</td>
<td>15.1</td>
</tr>
<tr>
<td>1933</td>
<td>212.7</td>
<td>11.2</td>
<td>12.9</td>
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<td>1934</td>
<td>171.6</td>
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<td>1935</td>
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<td>1937</td>
<td>269.9</td>
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<td>17.9</td>
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<tr>
<td>1938</td>
<td>235.8</td>
<td>13.3</td>
<td>20.4</td>
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<tr>
<td>1939</td>
<td>238.9</td>
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<tr>
<td>1940</td>
<td>252.5</td>
<td>15.3</td>
<td>16.2</td>
</tr>
<tr>
<td>1941</td>
<td>231.9</td>
<td>16.8</td>
<td>18.2</td>
</tr>
<tr>
<td>1942</td>
<td>272.4</td>
<td>19.5</td>
<td>19.0</td>
</tr>
<tr>
<td>1943</td>
<td>254.0</td>
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<td>1944</td>
<td>299.4</td>
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<td>1945</td>
<td>254.1</td>
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<td>1946</td>
<td>235.8</td>
<td>17.2</td>
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<tr>
<td>1947</td>
<td>266.6</td>
<td>18.2</td>
<td>16.3</td>
</tr>
<tr>
<td>1948</td>
<td>313.3</td>
<td>17.9</td>
<td>21.3</td>
</tr>
<tr>
<td>1949</td>
<td>281.8</td>
<td>14.5</td>
<td>22.3</td>
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<tr>
<td>1950</td>
<td>269.0</td>
<td>16.5</td>
<td>21.7</td>
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<td>1951</td>
<td>269.4</td>
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<td>1955</td>
<td>417.0</td>
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<td>409.2</td>
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</tr>
<tr>
<td>1957</td>
<td>388.3</td>
<td>21.7</td>
<td>23.2</td>
</tr>
<tr>
<td>1958</td>
<td>489.0</td>
<td>27.0</td>
<td>24.2</td>
</tr>
</tbody>
</table>

1/ Average live weight of cattle slaughtered under Federal inspection.

NOTE: Cotton, tobacco, and peanut yields measured in pounds per acre; milk production is in pounds per animal.

SOURCE: See Table II

FIGURE 3
TRENDS IN YIELDS OF SELECTED FARM PRODUCTS
1925 - 1958
NOTE: Yields measured in bushels per acre.
SOURCE: See Table II

FIGURE 4
TRENDS IN YIELDS OF SELECTED FARM PRODUCTS 1925-1958
increase in productivity from 1925 to 1957 was 1.4 percent and from 1940 to 1955, 1.5 percent.\(^1\) This increasing rate of productivity shows the extent to which new products and techniques are being applied—the final useful results of basic research.

**Savings from Increased Productivity**

If the productivity had not increased at a rate of 1.4 percent annually from 1925 to 1957—that is, if 1957 production had been achieved with 1925 technology—the total inputs of $23 billion (in 1957 dollars) would have been $10.35 billion higher. This amount is viewed as a savings in inputs of $10.35 billion.

Agricultural production in 1980 is estimated at 54 percent more than in 1957. This estimate is based on U.S. Bureau of Census population projections and per capita food consumption trends. Using an increasing rate of productivity of 1.5 percent per year, the estimated 54 percent increase in production by 1980 will require only a 14 percent increase in inputs. This is a conservative estimate because the rate of increasing productivity will undoubtedly continue to rise. For example, during the period from 1957 to 1980, labor productivity is expected to increase over 30 percent.

If 1957 techniques and prices were employed to produce the projected output until 1980, the total inputs would average $4.5 billion more per year than if the projected output until 1980 is produced with increasing levels of productivity. This $4.5 billion per year is viewed as a savings in inputs which total over $100 billion over the 23-year period.

This analysis is not altogether conclusive, but it does give an indication of the magnitude of benefits expected from increasing productivity which is dependent on increasing levels of technology. Dissemination and application of new knowledge acquired in a large measure through research is responsible for our rising levels of technology.

\(^1\) An estimate made by the USDA based on certain selected inputs. Possible Methods of Improving the Parity Formula, Report of the Secretary of Agriculture, 85th Congress, 1st Session, Document No. 18. February 1957.
Section IV

BENEFITS FROM THE AVAILABILITY AND USE OF RADIOISOTOPES

Measured by increasing productivity, the economic benefits ultimately derived from agricultural research are of considerable value. Estimating that part of the economic benefits which may be attributed to the use of radioisotopes, it is first necessary to examine the part played by radioisotopes in the over-all research program, to enumerate fields in agricultural science in which radioisotope methodology may be used, and to appraise potential research results in terms of possible savings and increased returns.

Research Using Radioisotopes in Perspective

Radioisotopes are an important new research tool for 3 reasons: they exhibit essentially the same chemical behavior as their nonradioactive counterparts, they can be detected and measured with ease and accuracy, and they exhibit nuclear reactions that are effective in producing ultimately beneficial mutations.

In 1958 the Agricultural Research Service reported 82 active agricultural research projects using radioisotopes out of a total of 2,872 projects. The average annual expenditure for the 82 projects was $25,000, a total of $2,050,000. In 1958, agricultural experiment stations conducted research projects using radioisotopes with a total expenditure in the range of $3 to $4 million.

The Atomic Energy Commission's program for agricultural research has an estimated annual budget of $3 million that is divided about evenly between on-site and off-site research. A large part of the off-site expenditures would be in the form of support for the research organizations mentioned above. The on-site research is underway at all of the AEC National Laboratories and at most of the large on-site AEC facilities.

There are a number of other federal agencies supporting radioisotope research directly or indirectly related to agriculture, such as the National Institutes of Health. There are at least 5 major chemical companies, 5 manufacturing concerns, and 4 private research organizations also engaged in agricultural research using radioisotopes. The total expenditure for this research is about $1 million annually.
All agricultural research projects represent a total annual expenditure of about $200 million. (See Table IV.) Of this total an estimated $7.5 to $8.5 million, or about 4 percent, are representative of agricultural research using radioisotopes.

Every phase of research is affected by and effects other phases. Agricultural research using radioisotopes is not independent of other research. Techniques and knowledge developed in one project may be of use in another perhaps with less or far greater significance. Techniques and data are shared by all of the life sciences so that economic benefits derived from agricultural research using radioisotopes cannot be found in agriculture alone, nor do all of the economic benefits to agriculture come from agricultural research.

Carry-over benefits proceed from as well as to agricultural research. Carry-over is most often on a basic research level. A better understanding of the process of photosynthesis that is discussed in Appendix A, in the study "Radioisotope Applications in the Study of Plant Physiology," will be useful to many fields of research. Radioisotope methodology and the data it helps to develop, described in the studies in Appendix A, will contribute to the general fund of scientific knowledge and have widespread intrinsic and economic benefits.

An example of a possible benefit from agricultural research using radioisotopes is control of the hazard to man of fallout from nuclear explosions. Such control may possibly be developed from a better understanding of the reaction of fission products in the metabolism of plants and animals. Another example is the possible control of the spread of disease to man by insects from a better understanding of insect behavior and physiology or eradication of different insect species from different areas.

Benefits from Selected Projects

The projects of agricultural research whose investigations are proceeding to reduce agricultural losses or otherwise increase productivity should be the ones whose economic benefits are most easily evaluated. Control and eventual elimination of the causes of production losses are the goal of many research projects. Table V shows estimated production losses for selected years due to various causes.

Infestation

Most dramatic results were obtained by radiation of male screwworm flies--pilot operations that were conducted on the Antilles island of
## Table IV

**UNITED STATES FARM PRODUCTION INDEX**  
AND AGRICULTURAL RESEARCH EXPENDITURES  
1925-1958

<table>
<thead>
<tr>
<th>Year</th>
<th>Index of Farm Production 1947-1949=100</th>
<th>Research Expenditures by USDA and State Experiment Stations</th>
<th>Index of Total Research Expenditures 1947-1949=100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Livestock</td>
<td>Crops</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1925</td>
<td>71</td>
<td>78</td>
<td>70</td>
</tr>
<tr>
<td>1926</td>
<td>74</td>
<td>80</td>
<td>73</td>
</tr>
<tr>
<td>1927</td>
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<td>79</td>
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</tr>
<tr>
<td>1928</td>
<td>76</td>
<td>82</td>
<td>73</td>
</tr>
<tr>
<td>1929</td>
<td>77</td>
<td>79</td>
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<td>1930</td>
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<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
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1/ Deflated by an index of government purchases of goods and services.

Table V

ESTIMATED LOSSES TO AGRICULTURAL PRODUCTION FROM VARIOUS HAZARDS
Average Annual Estimates for 1942-1951

<table>
<thead>
<tr>
<th>Item and Cause of Loss</th>
<th>Loss in Value</th>
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<tbody>
<tr>
<td></td>
<td>Amount</td>
</tr>
<tr>
<td></td>
<td>(millions of dollars)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Crops and Livestock</strong></td>
<td></td>
</tr>
<tr>
<td><strong>During production of crops, pastures, and ranges</strong></td>
<td></td>
</tr>
<tr>
<td>Diseases of crops</td>
<td>$2,847</td>
</tr>
<tr>
<td>Insects attacking crops</td>
<td>$1,942</td>
</tr>
<tr>
<td>Mechanical damage, hail, and weeds</td>
<td>$2,413</td>
</tr>
<tr>
<td>Harvesting losses</td>
<td>$1,096</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>$8,300</td>
</tr>
<tr>
<td>Pastures and ranges (diseases, fire, grasshoppers, and weeds)</td>
<td>$981</td>
</tr>
<tr>
<td>Losses during Production of Crops, Pastures, and Ranges</td>
<td>$9,281</td>
</tr>
<tr>
<td><strong>After production of crops, pastures, and ranges</strong></td>
<td></td>
</tr>
<tr>
<td>Farm storage losses (other than from insects)</td>
<td>$382</td>
</tr>
<tr>
<td>Storage losses from insects</td>
<td>$217</td>
</tr>
<tr>
<td>Crop losses during marketing</td>
<td>$303</td>
</tr>
<tr>
<td>Losses during processing of crops (diseases, parasites, and insects)</td>
<td>$2,688</td>
</tr>
<tr>
<td>Livestock, poultry, and their products</td>
<td></td>
</tr>
<tr>
<td><strong>Losses after Production of Crops, Pastures, and Ranges</strong></td>
<td>$3,861</td>
</tr>
<tr>
<td><strong>Total Losses to Crops, Pastures, Ranges, Livestock and Products</strong></td>
<td>$13,142</td>
</tr>
</tbody>
</table>

1/ Except as noted, the percentage figures represent losses from potential production, in other words, actual production ($27.6 billion) plus estimated loss ($13.4 billion), a total of $41.0 billion. This is the value of crops, livestock, and forest products that would have been produced if the losses had not occurred.

2/ The value of $1,942 million in this table includes crop losses of $991 million from about 75 insects on which detailed estimates were made. Using that as a sample, it is estimated that the loss from the remaining several thousand species attacking United States crops was $951 million. Total losses to crops, livestock, forests, fabrics, households, and buildings from all insects have been estimated at $3,600 million and the cost of control measures at $400 million.

Curacao and near Orlando, Florida, were successful in elimination of the screwworm infestation. On the basis of their success, a program has been set up to eliminate this pest from all of Southern Florida. Geographical differences in Texas, another residual area of the screwworm fly, will make elimination of this pest from all of our Southland a more difficult task.

Elimination of the screwworm infestation in Florida by radiation of the males of the species indicates a current annual savings in livestock production of $20 million. Comparable future savings in the Southwest could amount to as much as $35 million. Further economic benefits can be expected as an indirect result of this project. It is feasible that radiation sterilization techniques can be developed to control or eliminate other species responsible for losses in agricultural production. A similar pattern of approach could be effective in the control of several fruit flies in Hawaii. Innovations of the pattern may eventually lead to the control or elimination of such pests as the cotton bollweevil (cause of an estimated annual loss of $250 million), the sugar-cane borer (cause of an estimated annual loss of $4 million), the white-pine weevil, and others.

In the United States, the total loss caused by insects to agriculture is estimated at about $4 billion a year.\(^1\) Basic research using radioisotope techniques is being conducted in the belief that a better understanding of the physiology and behavior of insects will contribute to the development of methods for the control of agricultural losses due to insects. The problem is being approached not only as discussed above, but also by the development of insecticides. The use of radioisotope tracer techniques is indispensable in investigating insect biochemical processes. Knowledge of these processes is essential to the development of effective insecticides.

The use of 300 million pounds of "toxic" insecticides per year in the United States is a potential hazard to the population. Accuracy and sensitivity of measurement of residual levels of insecticides in food, feed, and forage crops is possible with the use of radioisotope techniques and, thus, affords increased public safety.

A tabulation of 111 selected agricultural research projects using radioisotopes at 24 experiment stations was made from data acquired by

\(^1\) G. J. Haeussler, Insect--The Yearbook of Agriculture for 1952, 1953, pp. 141-146.
questionnaire. (See Appendix B.) Although of the 13 projects that are related to the study of insects, only 1 evaluated its probable economic benefits; the other projects were believed to have great potential. The evaluation that was made was an estimated annual savings of $4 million to the livestock industry from the study of the mode of action of insecticides and anthelmintics.

Other studies that will be effective in the reduction of losses to the agricultural industry are those that are concerned with weeds and plant and animal diseases. The loss caused by plant diseases is estimated at $3 billion per year; the loss caused by weeds is estimated at $4 billion per year.

The 24 experiment stations reported 18 projects using radiosotopes that are related to problems caused by weeds and diseases. Two of the 18 projects estimated their potential economic benefits; both studies were concerned with the effectiveness and residual levels of herbicides. One project evaluated its economic benefit at $10 million per year from a 25 percent decrease in the state's loss of forage crop; the other, $20 million per year from savings in losses in U.S. row crops.

Mutations

Selective breeding of livestock and crop plants is another way to cut agricultural production losses and otherwise increase productivity. The use of irradiation to induce mutations allows a breeder to study more variations than would otherwise be possible. This technique has been applied to crop plants with great success, but because of the costly waste involved, it is not used extensively in animal breeding. More economically feasible control of animal breeding has been gained by the study of their physiological and biochemical processes which are discussed briefly under nutrition and in Appendix A.

Exposing a crop plant to irradiation produces varieties whose characteristics are different from its antecedents. Many undesirable varieties must be wasted, but by selection of varieties with good production characteristics, breeders have been able to develop plants that are more

resistant to disease, that are more amenable to mechanical harvesting, and that have a better food value and higher yield per acre.

Small grain improvement by breeding and selection with radiation-induced mutations includes an oat variety that is resistant to crown rust and has a better yield and a rye variety that has a greater degree of self-fertility. On a national basis, these improvements will probably save millions of dollars. Research workers in Surinam, a Netherland's colony in South America, have isolated radiation-induced mutants in rice that have shorter straw and are resistant to certain diseases. Breeders are working on corn mutants that are resistant to root and stem rot diseases. It has been estimated that the control of one of the 3 or 4 diseases affecting corn would increase the yield by 25 percent.

Mutation studies using radioisotopes have been done on over 60 different crop plants. Each percentage point increase in crop yield can mean millions of dollars of additional income to farm operators whether it is derived from a reduction of the $3 billion annual loss due to plant diseases, from the increased sales appeal of an apple variety, or from the development of an early maturing grain with less straw.

**Nutrition**

New knowledge of the metabolic and growth processes of plants and animals will allow the farm operators to make the most efficient use of natural and added nutrients. Increased efficiency will result in savings to the agricultural industry. The technical details of the radioisotope methodology for the study of plant and animal metabolic and growth processes are found in the consultants' studies in Appendix A.

In 1957, more than $1.25 billion was spent on fertilizers and lime in the United States. Increasing the efficiency of their use can mean millions of dollars of savings to the agricultural industry.

In the field of plant nutrition, phosphate fertilizers have received the most attention. The knowledge and experience gained from extensive research and field tests indicate that it is reasonable to expect a 10 percent reduction in the current $150 million spent for phosphate fertilizers—an annual savings of $15 million. A research scientist from one of the 24 experiment stations estimates that phosphate fertility research will increase the yield of sugar beets, barley, and potatoes by 20 percent and alfalfa by 50-75 percent to give an annual benefit of about $32 million from the more efficient use of phosphate for these crops alone.
Whether or not research work with the other macro-elements (N, K, Ca, Mg, and S) and micro-elements (Fe, Mn, Zn, Mo, B, Cu, and Cl) that are essential to plant growth, will result in relative estimated savings is impossible to know. However, some individual studies of these elements using radioisotopes in research have had encouraging results.

In Oregon, sulfur is a limiting nutrient in 1/4 to 1/3 of the soils. Oregon farm operators applied about $800,000 worth of sulphate material to the soil each year. Radioisotope research indicated that not all types of soil respond to the sulphur treatment. It is estimated that about 10 percent of the $800,000 or $80,000 a year could be saved by more efficient use of sulphate materials in Oregon.

Tip burn of potato foliage causes about 5-10 percent reduction in the yield of potatoes. Radioisotope research has indicated that this disorder is caused by Ca deficiency and remedied by foliar applications. The true cause of the disease and the mechanism for its control have not yet been found, but a 5-10 percent increase in the yield of potatoes would represent a significant economical benefit. Studies of the peanut plant, using the same Ca\textsuperscript{45} tracer techniques, have already established that the downward movement of Ca from the plant to the fruit is inadequate and that Ca must be applied to the fruiting area for maximum yields. It is estimated that proper application of Ca to the peanut plant will yield additional returns of millions of dollars.

The physical characteristics of soil affect plant nutrition. Radioisotope techniques are being used to help find the effect of aeration of soil on plant nutrition. Because the study is only in its fundamental stages, economic evaluations are difficult. It is hoped that irrigated crop yields will be increased by 10-20 percent which might eventually amount to savings of from $15-25 million.

Methods developed by the study of hormones and other growth regulators may possibly have revolutionary effects on the agricultural industry. The general objectives of the experiments are to increase production, reduce labor costs, and decrease environmental losses.

Pineapple production has already been put on an assembly line basis with fields ripening in succession as needed. These production methods are possible in a tropical climate with the use of growth regulators. A great deal of research is necessary to gain a sufficient understanding of the growth process to allow control of fruiting in different crops. Innovation and diffusion of the methods used to control pineapple production will be applicable to this work.
Where climate is a problem, it can be modified only to a limited extent, but methods and plant breeds can be developed to be more adaptable to the climate. Studies are in progress on the mechanism of action of growth inhibitors that are able to prolong the dormant period of fruit trees. Ultimate control of the mechanism would allow the farm operator to prevent spring frost injury.

Chemical thinning sprays are used on apples and peaches for control of preharvest drop. Thinning increases yields—a 20 percent annual production increase is hoped for. And thinning sprays reduce production costs by saving on hand labor.

Relative possible savings can be found in the livestock and poultry industries—savings made possible by the use of radioisotopes in agricultural research.

Fundamental information developed in the study of thyroid physiology in chickens and turkeys should result in strains of birds with greater feed utilization. It is estimated that a 20 percent increase in feed utilization will be gained. Studies on the minerals that are essential to poultry nutrition will develop information that changes standard feed practice. An increase in the efficiency of feed conversion may result in savings of $3 million in one state alone.

Studies of the thyroid physiology are also being conducted on cattle. It is believed that there is a relationship between thyroid activity and the productive capacities of dairy cattle and between thyroid activity and the temperature of the environment. With these points as a basis, research is proceeding to develop dairy cattle capable of better production during the hot summer months in the southern states.

Radioactive selenium is being used in studies on the effect of selenium on growth, reproduction, and the mechanism of intoxication in livestock. At present livestock losses due to selenosis are estimated at over $200,000 per year. Limited weight gain and loss of fertility probably cause an added equal loss.

Evaluation of Benefits from Radioisotope Use

The benefits from projects using radioisotopes cannot just be added together to evaluate the use of radioisotopes in research. Many projects are in such fundamental stages no estimate can be made. The selected projects discussed in this section have a more direct relationship with increased productivity, but it can be readily seen that a total of their
estimated evaluations would have little meaning. Each phase of research is interwoven with others.

If we use the poultry production examples, it is clear that benefits from breeding and nutrition may be one and the same. Good nutrition—optimum mineral levels in feed—is expected to result in a savings. Iodine, for example, is expected to aid in improved breeding. Whether or not these benefits will be one and the same, separate and should be added, or separate and will react as factors on one another, it is not now possible to know.

The problems of increasing agricultural productivity are being approached in many ways in all the fields of agricultural research. The problem of agricultural losses due to diseases are being solved by creating disease resistant mutants, by controlling or eliminating disease carrying insects, and by learning more about nutritional requirements. The problems of losses due to weeds are being solved by soil studies and by the development of herbicides which are essentially growth regulators. Many of the different projects utilizing radioisotope techniques will help to solve the same problems.

With the expected population explosion in mind, this process has great significance. Increased agricultural productivity is important to public well-being and should receive a high degree of attention.

A broad base of knowledge and experience are needed to project 20 years into the future. Because radioisotopes are a relatively new research tool, the economic benefits from the use of radioisotopes in agricultural research must be evaluated as a part of all agricultural research.

Earlier in this report it was projected that between 1957 and 1980 savings in agriculture due to increasing productivity will probably be a minimum of $4.5 billion per year. A major part of this savings should be credited to knowledge accumulated over many years through the efforts of numerous research workers.

Expenditures for agricultural research involving radioisotopes are at the present time estimated to be about 4 percent of total agricultural research expenditure. If this level is maintained, then savings attributable to radioisotopes would average a minimum of about $180 million per year between 1957 and 1980.
Section V

ANALYSIS OF RADIOISOTOPE USE AT EXPERIMENT STATIONS
AND OTHER ORGANIZATIONS

The pertinent data obtained from responses to questionnaires which were sent to all research organizations using radioisotopes that could conceivably be engaged in work pertaining to the agricultural industry have been analyzed. The method used to obtain and select the data is described in Appendix B along with detailed tabulations of the data from selected responses. Because the Agricultural Experiment Stations at land-grant colleges were sent a different questionnaire than other research organizations, it is convenient to divide our analysis of the responses into two groups--Agricultural Experiment Stations and other research organizations.

Agricultural Experiment Stations

In general, the research programs of the stations are oriented to the specific problems facing the agricultural industry in their respective states. For example, more cotton is grown in Texas than in any other state, but the yield per acre is not as high as in areas where cotton is grown under irrigation. The experiment station in Texas reports basic research projects underway in the fields of plant physiology, genetics, cytology, and pathology with studies on soil and water that are directed toward the eventual development of an irradiation-induced cotton mutant capable of higher yields under Texas conditions. Studies in entomology are directed primarily toward the control or elimination of the cotton boll weevil that causes damages estimated at $10-20 per acre. With its wide open spaces, Texas leads all the states in the number of livestock it raises. The same fields of research applied to cotton production, whose by-products are used as livestock feed, are applied to the production of small grains, Dallis grass, and other native grasses. Research projects in the fields of animal physiology, genetics, and pathology are underway to determine the interrelationship of essential fatty acid, phospholipide, and cholesterol metabolism. This work may indicate a health relationship between the ingestion of fats and the kind of fats ingested on a long-term basis, it could affect the consumption of fatty goods, or, at least, the ratio in the kinds of fatty food produced by agriculture.
Wisconsin, known as "America's Dairyland," produces more milk and cheese than any other state. Its main crops--hay, corn, oats--are grown for the dairy industry. Other crops are: sugar beets, potatoes, vegetables, strawberries, and tobacco. The agricultural research projects underway in Wisconsin include: the study of basic biochemistry and physiology of animals, the study of rumen physiology, the study of the biological activity of insecticidal derivatives, etc. These basic research projects are directly or indirectly concerned with the dairy industry. Other projects are concerned with fertilizer uptake, placement, and timing; herbicides; the mechanism of biological $N_2$ fixation; and soil studies. These basic research projects are indirectly concerned with the dairy industry and directly concerned with ultimately more efficient crop production. Study on the mechanism of growth inhibitors is also being conducted in Wisconsin where the temperature is below freezing much of the time during the winter months and often during the spring months.

Six agricultural research projects using radioisotopes were reported by the New York Agricultural Experiment Station. Two of these were directed to the eventual elimination of problems causing production losses in New York's large dairy industry, and two toward increasing its productivity through more efficient nutritional practices.

While one can come close to identifying the problems of the experiment station and the state by observing the fields in which isotopes are being used, the problems or radioisotope applications are by no means unique to the state. Knowledge gained in any one state will help to solve the problems existing in many states. The examples used above can illustrate this. Knowledge gained in Texas, Wisconsin, and New York will be of value to the livestock and dairy industries in the respective states and to other states, such as Florida with its growing livestock industry, as well. Knowledge gained in Wisconsin that may eventually lead to growth control could be of value to orchard operators in California, Oregon, Washington, New York, etc.

Table VI shows the isotopes most frequently used. Isotopes $^{32}$P and $^{14}$C appear to be the most valuable by a factor of at least two over any of the others reported, but analysis of the survey data showed that those experiment stations nearest the reactors are the most frequent users of isotopes with short half-lives and that more distant stations more frequently employ such standard convenient isotopes as $^{14}$C, $^{32}$P, $^{35}$S, and $^{45}$Ca. This suggests that more isotopes would probably be used, especially those with short half-lives if they were more readily available.
Table VI

MAJOR RADIOISOTOPES USED BY
THE REPORTING EXPERIMENT STATIONS
Fiscal Year 1958-59

<table>
<thead>
<tr>
<th>Radioisotopes</th>
<th>Number of Projects Using Radioisotopes</th>
<th>Half-Life</th>
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<tbody>
<tr>
<td>P 32</td>
<td>129</td>
<td>14.3 d</td>
</tr>
<tr>
<td>C 14</td>
<td>107</td>
<td>3 (5.6 \times 10^3) y</td>
</tr>
<tr>
<td>S 35</td>
<td>53</td>
<td>87.1 d</td>
</tr>
<tr>
<td>Ca 45</td>
<td>52</td>
<td>164 d</td>
</tr>
<tr>
<td>H 3</td>
<td>21</td>
<td>245 d</td>
</tr>
<tr>
<td>Zn 65</td>
<td>20</td>
<td>12.3 y</td>
</tr>
<tr>
<td>Cl 36</td>
<td>16</td>
<td>3.2 (\times 10^5) y</td>
</tr>
<tr>
<td>Fe 55 and Fe 59</td>
<td>14</td>
<td>2.94 y and 45.1 d</td>
</tr>
<tr>
<td>I 131</td>
<td>13</td>
<td>8.05 d</td>
</tr>
<tr>
<td>Sr 89 and Sr 90</td>
<td>13</td>
<td>51 d and 28 y</td>
</tr>
<tr>
<td>K 42</td>
<td>7</td>
<td>12.5 h</td>
</tr>
<tr>
<td>Rb 86</td>
<td>5</td>
<td>18.6 d</td>
</tr>
<tr>
<td>Mo 99</td>
<td>6</td>
<td>67 h</td>
</tr>
<tr>
<td>Cr 51</td>
<td>3</td>
<td>27.8 d</td>
</tr>
<tr>
<td>Mn 54</td>
<td>3</td>
<td>300 d</td>
</tr>
<tr>
<td>Cs 137</td>
<td>3</td>
<td>30 y</td>
</tr>
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</table>

Note: The reporting stations are shown in Table VIII.

Source: Stanford Research Institute.
Table VII shows the number of experiment stations that used radioisotopes in specific scientific fields in fiscal year 1958-59. This table clearly shows that the extent of use of isotopes has already become quite widespread through the agricultural sciences. Adding the number of research problems using radioisotopes in the specific fields gives a total larger than the actual number of projects underway at the stations tabulated. This is due to the fact that work directed toward the eventual solution of any one problem almost always involves factors from several fields of research and may eventually help to solve more than one problem. The stations reported that about 18 percent of their research effort using radioisotopes was in soil and water sciences, 41 percent in plant sciences, and 41 percent in animal sciences.

Institutions with the largest scientific research programs in a field or fields make the most use of radioisotopes. Reviewing the research underway at a given experiment station, it became evident that many departments in the land-grant colleges that carry on general agricultural research with the experiment stations, such departments as agronomy, agricultural chemistry, zoology, animal husbandry, etc., have not yet started to use radioisotopes. If radioisotope methodology that is already developed is given more widespread support and use, its applications will benefit research and create a greater demand for isotopes.

On the basis of discussions with directors of several experiment stations as well as with many department heads of land-grant colleges, it is clear that the use of radioisotopes will expand at these institutions. Instead of the present average of one department with two projects involving the use of radioisotopes at all land-grant colleges, probably five or six departments with at least two projects each will be using radioisotopes in research work in the future.

This projected increase will be achieved in the next 5 to 10 years if the greatest difficulty in the use of radioisotopes is resolved—the problem of training research personnel. The number of staff members in the physical and biological sciences at land-grant colleges was found to have increased less than 20 percent from 1953 to 1957, while personnel using radioisotopes increased about 200 percent during the same period and that an even greater increase would be of value. On the basis of interviews with about fifty staff members of twenty experiment stations, it was found that probably the primary reason many departments have not started the use of radioisotopes is lack of trained personnel. It appears to be mostly a matter of the cost of training a man to effectively use isotopes.
Table VII
FIELDS OF AGRICULTURAL RESEARCH USING RADIOISOTOPEs
AT REPORTING EXPERIMENT STATIONS
Fiscal Year 1958-59

<table>
<thead>
<tr>
<th>1. Soils and Water</th>
<th>II. Plant—Physiology, Genetics Cytology, Pathology</th>
<th>III. Animals—Physiology, Genetics, and Pathology (continued)</th>
<th>IIIIB. Entomology (continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Stations</td>
<td>Number of Stations</td>
<td>Number of Stations</td>
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<tr>
<td>1. Irrigation</td>
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<td>2</td>
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<td>Management problems</td>
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<td>Requirements</td>
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<td>Deficiency symptoms</td>
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<td>12</td>
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<td>6</td>
<td>12</td>
<td>Vitamins, tranquilizers</td>
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<td>7</td>
<td>2</td>
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<td>Aeriation</td>
<td>9</td>
<td>1</td>
<td>Fertilization</td>
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<tr>
<td>Structure</td>
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<td>5. Breeding of improved forms</td>
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<tr>
<td>Mineral and organic make-up</td>
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<td>2</td>
<td>Other</td>
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<td>I. Thermal radiation and</td>
</tr>
<tr>
<td></td>
<td>81</td>
<td>72</td>
<td>temperature</td>
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<td></td>
<td>82</td>
<td>73</td>
<td>1. Insect dispersal</td>
</tr>
<tr>
<td></td>
<td>84</td>
<td>75</td>
<td>3. Requirements</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>76</td>
<td>4. Utilization of nutrients</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>77</td>
<td>5. Efficiency study</td>
</tr>
<tr>
<td></td>
<td>87</td>
<td>78</td>
<td>I. Thermal radiation and</td>
</tr>
<tr>
<td></td>
<td>88</td>
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<td>temperature</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>80</td>
<td>1. Insect dispersal</td>
</tr>
<tr>
<td></td>
<td>91</td>
<td>82</td>
<td>3. Requirements</td>
</tr>
<tr>
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<td>92</td>
<td>83</td>
<td>4. Utilization of nutrients</td>
</tr>
<tr>
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<td>93</td>
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<td>98</td>
<td>89</td>
<td>3. Requirements</td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>90</td>
<td>4. Utilization of nutrients</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>91</td>
<td>5. Efficiency study</td>
</tr>
</tbody>
</table>

1/ The reporting Agricultural Experiment Stations included here were those of the land-grant colleges in the following states: Wisconsin, Delaware, Connecticut, Colorado, Arizona, Alabama, Florida, Georgia, Hawaii, Iowa, Kentucky, Kansas, Massachusetts, Maryland, Mississippi, Missouri, Nebraska, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Indiana, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Washington, Wyoming, and West Virginia.

2/ None reported.

Source: Stanford Research Institute.
Table VIII shows the number of programs at stations by annual expenditure level. Each program has been placed in one of six brackets, from "$2,500 and less" to "$30,000 and over," in each of five major fields of agricultural research for three periods--fiscal year 1958-59, fiscal year 1959-60, and expenditures which would be made if the stations had the support they desire in this research. This table shows that from 1958-59 to 1959-60 there is to be a sizable general increase planned in expenditures for all fields except engineering, and that the desired level of expenditures is considerably above that planned for 1959-60. It is important to realize that of these expenditures for research projects that involve radioisotope methodology, only a small proportion of the money involved will actually be used for procurement and handling of isotopes, but that isotopes play a significant role in the experiments.

Survey of Other Organizations

Positive responses to the questionnaire on the use of radioisotopes in agricultural sciences were received from 16 educational institutions (including 2 holders of broad coverage licenses) and from 12 industrial organizations. The positive responses reported a total of 104 projects using radioisotopes in agricultural sciences, but they furnished only part of the information requested about these projects. In general, their responses supported the findings from the survey of the land-grant colleges.

The 16 educational institutions reported 53 projects underway. Only 12 institutions estimated expenditures on agricultural research using radioisotopes. The budgets ranged from $1,400 to $80,000 for fiscal year 1958-59 and averaged $26,255. The average budget per project was $5,312. The man-years planned for the projects were reported by only 10 institutions and averaged 3.1 man-years per institution. The percent of the total agricultural research expenditure represented by research using radioisotopes was reported by 13 of the institutions. Over half reported 75 percent or more and all were over 4 percent. Eleven of the institutions estimated the probable use of radioisotopes in their agricultural research in the next 5 years. Four plan to more than double their use while four others plan no increase. Of the nine reporting on probable increase in their total agricultural research, four said no increase and only one estimated as high as twice as much.

The 12 industrial or private research organizations reported 51 projects underway. Only 5 of the organizations estimated expenditures on agricultural research using radioisotopes. The budgets varied from
Table VIII
SIZE AND NUMBER OF RESEARCH PROGRAMS INVOLVING RADIOISOTOPES
AT 36 AGRICULTURAL EXPERIMENT STATIONS

<table>
<thead>
<tr>
<th></th>
<th>Fiscal Year 1958-59</th>
<th>Fiscal Year 1959-60(^1)</th>
<th>Desired Level of Expenditures(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I  II  III  IV  V  VI</td>
<td>I  II  III  IV  V  VI</td>
<td>I  II  III  IV  V  VI</td>
</tr>
<tr>
<td>Agricultural Sciences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soils and Water</td>
<td>20  20  11  5  3  5</td>
<td>18  20  14  8  3  2</td>
<td>11  17  22  12  7  3</td>
</tr>
<tr>
<td>Plant Sciences</td>
<td>59  31  31  18  3  15</td>
<td>50  40  31  24  4  12</td>
<td>19  29  35  48  12  20</td>
</tr>
<tr>
<td>Animal Sciences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Including Veterinary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medicine</td>
<td>38  20  24  19  3  13</td>
<td>40  22  25  18  5  10</td>
<td>13  15  39  25  9  16</td>
</tr>
<tr>
<td>Entomology</td>
<td>10  2   9  3  4  5</td>
<td>10  4   7  6  3  1</td>
<td>9   1   9  7  5  3</td>
</tr>
<tr>
<td>Engineering</td>
<td>1  ---  1  ---  1</td>
<td>1  2   1  1  ---  1</td>
<td>1  ---  1  2  1</td>
</tr>
</tbody>
</table>

Notes: Numbers heading the columns represent expenditures as follows:

Group  I  $2,500 and less
       II  2,500 to 4,999
       III 5,000 to 9,999
       IV 10,000 to 19,999
       V 20,000 to 29,999
       VI 30,000 and over

This table is based on the information provided in the circulars sent to the Agricultural Experiment Stations. Experiment Stations included were those at the land-grant colleges of the following states: Wisconsin, Delaware, Connecticut, Colorado, Arizona, Alabama, Florida, Georgia, Hawaii, Iowa, Kentucky, Kansas, Massachusetts, Maryland, Mississippi, Missouri, Nebraska, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Indiana, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Washington, Wyoming, and West Virginia. California is included for fiscal year 1958-59 only.

\(^1\) These periods were not as completely reported as the FY 1958-59 period.

Source: Stanford Research Institute.
$6,000 to $25,000 for fiscal year 1958-59 and averaged $20,000. The average budget per project was $5,825. The man-years planned for the projects were reported by only 5 organizations and averaged 2.25 man-years per organization. The percent of the total agricultural research expenditures represented by research using radioisotopes was reported by all of the organizations with three reporting almost 100 percent, the rest less than 25 percent each. Nine of the organizations estimated the probable use of radioisotopes in their agricultural research in the next 5 years. Three plan on doubling their effort while the rest plan increases of one-third or less. Eight of the 9 estimated a probable increase in their total agricultural research; one quadrupling, the rest planning increases of 50 percent or less.

The responses indicated that many of the scientists engaged in basic research are reluctant to place an economic evaluation on their work. This reluctance is undoubtedly due to the time-lag discussed in Section III. A few evaluations that were made on 10 projects which were more directly related to commercial applications are tabulated below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Crop</th>
<th>Average Percent Change in Production</th>
<th>Average Dollar Change in Net Returns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliar fertilizers</td>
<td>Several crops</td>
<td>+ 200-1,000% yield/unit of fertilizer</td>
<td>(+10%/acre)</td>
</tr>
<tr>
<td>Defoliants</td>
<td>Cotton</td>
<td>+ 5% in quality</td>
<td>+ $10/bale</td>
</tr>
<tr>
<td>Systemic insecticides</td>
<td>Cotton</td>
<td>- 5% in cost of production</td>
<td>+ $5/bale</td>
</tr>
<tr>
<td>Fungicides</td>
<td>Vegetables</td>
<td>- 5% in crop loss</td>
<td>+ $2-5/acre</td>
</tr>
<tr>
<td>Feed sterilization</td>
<td>Animal feeds</td>
<td>- 10% in crop loss</td>
<td>+ $5-10/ton</td>
</tr>
<tr>
<td>Irrigation water</td>
<td>All crops</td>
<td>+ 10% in yield</td>
<td>+ $5-20/acre</td>
</tr>
<tr>
<td>New crop varieties</td>
<td>All crops</td>
<td>+ 10% in yield</td>
<td>+ $10-20/acre</td>
</tr>
</tbody>
</table>

The projects using radioisotopes in agricultural research at these institutions and organizations are generally the same type as those underway at the Agricultural Experiment Station. Table IX shows that the four most frequently used isotopes are the same isotopes most frequently used by the Agricultural Experiment Stations. About 30 percent of the 104 projects are primarily concerned with studies that will
## Table IX

**NUMBER OF OTHER ORGANIZATIONS AND THEIR PROJECTS USING RADIOISOTOPES**  
**Fiscal Year 1958-59**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Industrial</th>
<th></th>
<th></th>
<th></th>
<th>Educational</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Organizations</td>
<td>Projects</td>
<td>Organizations</td>
<td>Projects</td>
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<td>Projects</td>
<td>Organizations</td>
<td>Projects</td>
<td>Organizations</td>
<td>Projects</td>
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<tr>
<td>C¹⁴</td>
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<td>38</td>
<td>11</td>
<td>31</td>
<td>21</td>
<td>69</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td></td>
<td></td>
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<td>50</td>
<td>36</td>
<td>36</td>
<td>36</td>
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<tr>
<td>S³⁵</td>
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<td>4</td>
<td>18</td>
<td>9</td>
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<td>Fe⁵⁹</td>
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<td>1</td>
<td>6</td>
<td>3</td>
<td>8</td>
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<td>36</td>
<td>36</td>
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<td>Sr¹⁸⁵-⁸⁹-⁹⁰</td>
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<tr>
<td>Fission Products</td>
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<td>--</td>
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<td>Ce¹⁴⁴</td>
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<tr>
<td>Cs¹³⁷</td>
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<tr>
<td>Rw¹⁰⁶</td>
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<tr>
<td>I¹³¹</td>
<td>--</td>
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<td>3</td>
<td>5</td>
<td>3</td>
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<td>Co⁶⁰</td>
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<td>Na²⁴</td>
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<tr>
<td><strong>Total</strong></td>
<td>13</td>
<td>53</td>
<td>18</td>
<td>58</td>
<td>31</td>
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</tr>
</tbody>
</table>
ultimately aid in the reduction of losses due to insects, weeds, and diseases. About 50 percent of the projects are on the physiology and nutrition of plant and animals which may eventually result in increased agricultural production through greater efficiency and/or resistance to insects, weeds, and diseases. The remaining projects were in the fields of soil, 9 percent, and other sciences, 11 percent. One example will indicate why the other sciences are not classified. Studies on "Feed Storage" may be directed toward the reduction of losses due to stored-product pests or toward the reduction of losses of vitamins or other nutrient factors during storage.

It is interesting to note that the economic evaluations that were made in all of the questionnaires in terms of possible national savings in dollars per year, total $92 million, even though the response is only partial.
Section VI
CURRENT AND POSSIBLE FUTURE APPLICATIONS
OF RADIOISOTOPES IN AGRICULTURAL RESEARCH

This section summarizes the present and future applications of radioisotopes in agricultural research as they are discussed in the consultant studies in Appendix A. The studies concur in their general conclusions and emphasize points made in earlier sections of this report, although in some details they may differ.

Application of radioisotope techniques in agricultural research not only permits the attainment of information in less time, with greater ease, and with more accuracy than possible with more established techniques but also makes it possible to attain new information not possible with more established techniques. The application of radioisotopes—that is, the isotopes and equipment for handling them—is relatively inexpensive. The greatest difficulty in the development of their use is the current shortage of trained personnel.

Radioisotope applications have made and can be expected to make significant contributions in animal, plant, and soil sciences. The majority of current applications, the beginning of radioisotope research for agriculture, has been directed toward the reduction of agricultural production losses due to pest, diseases, and nutritional deficiencies. Future applications can be expected not only to aid in the control of losses but to increase agricultural production in other ways.

Farm Animal Sciences and Veterinary Medicine

Although this study of radioisotope research has been limited to applications concerned specifically with agricultural problems in animal sciences and veterinary medicine, it must be remembered that there is a carry-over from field to field in research. There is a carry-over to agricultural research from other fields, particularly of research work done with small animals by the medical profession. But significant research methodology is also carried from agriculture to other life sciences. The present and future applications in the animal sciences and their possible economic benefits summarized below can also have important implications in other fields.
With the perfection of appropriate techniques for the use of such isotopes as $^{45}\text{Ca}$ and $^{32}\text{P}$, the skeletal physiology and metabolism of farm animals can be measured with ease and accuracy, often without sacrificing the experimental animal. Study has determined the most beneficial amount of the dietary elements Ca, P, and F, but more studies are needed on other nutrients.

The belief that thyroid metabolism exerts a control on such production characteristics as reproduction, milk secretion, egg laying, wool production, growth, and fattening is an important incentive for the use of $^{131}\text{I}$ in study of the thyroid. More fundamental research is needed to gain some possible control of these processes.

From isotope dilution techniques for body water and other volume measurements, calculation of animal-body fat and protein and calorie content is possible. Volume measurements can be related to feed utilization, inheritance, environment, and physiological or pathological disturbances.

Studies of biochemical synthesis with radioisotopes and labeling techniques have proven indispensable in the determination of precursor-product relationships.

For more complete understanding and better evaluation of the potential fallout hazard to the population, it is necessary to study in detail the metabolism and movement of fission products in the food chain of agricultural animals.

The high cost of large farm animals as subjects for experimental radioisotope research has been a limiting factor. This problem will be somewhat alleviated by a recent (March 1959) memorandum by the U.S. Department of Agriculture stating that under certain conditions meat from animals which have been treated with radioisotopes may be sold.

Some of the possible future applications of radioisotopes in animal sciences and veterinary medicine are shown in Table X. The table indicates whether or not they are likely to be used in routine or basic research.

It is impossible to estimate the economic value of the applications as discussed. However, knowing that from 1942 to 1951 there was an average annual loss of livestock production of about $278$ million, it is possible to estimate the total value of the applications of radioisotopes for agricultural research.
Table X
SOME POSSIBLE FUTURE APPLICATIONS OF RADIOISOTOPES
IN ANIMAL SCIENCES AND VETERINARY MEDICINE RESEARCH

<table>
<thead>
<tr>
<th>Applications</th>
<th>Ca(^{45})</th>
<th>Sr(^{85}&amp;89) (^{1})</th>
<th>p(^{32})</th>
<th>C(^{14})</th>
<th>C(^{35})</th>
<th>(\Gamma_{131})</th>
<th>Fe(^{59})</th>
<th>C(^{64})</th>
<th>Cl(^{36})</th>
<th>C(^{57}&amp;58&amp;60)</th>
<th>H(^{3})</th>
<th>Mg(^{28})</th>
<th>Mg(^{28}&amp;24)</th>
<th>Zn(^{65})</th>
</tr>
</thead>
<tbody>
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<td>Metabolism</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mechanism of absorption</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X*</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
</tr>
<tr>
<td>Kidney function and excretory mechanisms</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>Liver function</td>
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</tr>
<tr>
<td>Distribution</td>
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<td>X</td>
<td>X</td>
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<td>S(\text{O}_{4})*</td>
<td>C(l)</td>
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</tbody>
</table>

Notes: X indicates isotopes used as a basic research tool.
X* indicates a routine use of isotopes.

\(^{1}\) As a research tool, Sr\(^{85}\&89\) is used for a contrast to or substitute for Ca\(^{45}\).

Source: Appendix A, pp. 60 to 71.
Table XI shows estimates made on this basis together with estimates on benefits from improved nutrition and selective breeding. The consultants noted that a large part of the $50 million annual savings from the use of radioisotopes in the prevention and treatment of bacterial and viral diseases should be attributed to research carried on in the biological sciences. These estimates list potential savings which total about $172.5 million per year.

Agricultural Entomology

In 1931 the use of \( \text{Pb}^{212} \) in lead arsenate for study of silkworms gave the application of radioisotopes in entomological research an early start. Their applications in the study of the processes of absorption, distribution, metabolism, and elimination of insecticides within insects, plants, and animals have been invaluable. Their application has also been helpful in gaining some understanding of how insects become resistant to an insecticide. This analysis of radioisotope application is limited to lines of research developing in agriculture with no evaluation of the effects of insecticides upon man and animals.

The application of radioisotopes in agricultural research has contributed and should continue to contribute to the reduction or extermination of different pest species from certain areas. Stored-product pests which cause losses estimated at 10-50 percent of the crops in different parts of the world are controlled by exposing the stored products and the pests feeding on them to irradiation. Sublethal irradiation is adequate since it decreases insect fertility.

Screwworm infestation has been responsible for an estimated annual loss of $10 to $25 million to the livestock industry. Sterilization by irradiation of laboratory reared screwworm flies has had spectacular results, the eradication of the pest in test areas. Dispersing sterilized flies in a large enough number to eliminate reproduction of the species was practical because of the relatively small screwworm population, its confined area of migration, and its reproductive instincts—the female of the species will accept only one insemination.

The same or a similar method may be affective in the control or elimination of other pest species. The African tsetse fly, several Hawaiian fruit flies, and some species of mosquitoes may be controlled or eradicated by the same pattern of approach, but the white-pine weevil and other pests would require a too large-scale operation. Innovations of the method of approach could possibly affect their control or elimination.
### Table XI
POSSIBLE ECONOMIC BENEFITS OF RADIOISOTOPES TO THE LIVESTOCK INDUSTRY
(Dollars in Millions)

<table>
<thead>
<tr>
<th>Cause of Loss</th>
<th>Average Annual Loss 1942-51</th>
<th>Percent Increase Production</th>
<th>Annual Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insect Pests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screwworm</td>
<td>$ 20(^1/)</td>
<td>100%</td>
<td>$ 20.</td>
</tr>
<tr>
<td><strong>Internal Parasites</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coccidiosis</td>
<td>50</td>
<td>20</td>
<td>10.</td>
</tr>
<tr>
<td>Cattle Grubs</td>
<td>11</td>
<td>30</td>
<td>3.3</td>
</tr>
<tr>
<td>Others</td>
<td>44</td>
<td>5</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Bacterial and Viral Diseases</strong></td>
<td>167</td>
<td>30</td>
<td>50.</td>
</tr>
<tr>
<td><strong>Nutritional Disorders</strong></td>
<td>89</td>
<td>25</td>
<td>22.</td>
</tr>
<tr>
<td>Heat (selective breeding of southern dairy cattle)</td>
<td>10</td>
<td>65.</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>$172.5</td>
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</tbody>
</table>

\(^1/\) Ed. note—Apparently excludes potential savings in the Southwest.

Source: Appendix A, pp. 71-76.
Insecticides are a major agriculture expense. The term "insecticide" includes all substances that are toxic to insects. Because 300 million pounds of insecticides are used in the United States each year, they are a potential source of danger to public safety. Public Law 518 protects the population from this hazard. It not only requires the registration of pesticides with recommendations for their use to give satisfactory insect control but also with recommendations for their use that will result in nontoxic residual levels in foodstuffs. The use of radioisotopes has been indispensable in the formulation of these recommendations because they have made it possible to measure accurately toxic and nontoxic changes due to insecticides in the metabolic processes of insects, animals, and plants. Radioisotopes have also been helpful in determining the effect of insecticides on the vitamin content of foodstuffs.

The radioisotope methodology used varies with the type of insecticide that is being studied. Several methods have been developed to determine residual levels and biochemical changes. Knowledge of the biochemical changes has contributed to a better understanding of the action of insecticides on living matter and the resistance to insecticides that different species develop.

Radioisotopes have been used advantageously in tagging compounds for the study of the behavior of insects, "especially their rate of movement and degree of dispersal under various conditions, their reaction to stimuli, the amount of fluid imbibed during sucking of plant juices, and the injection of saliva along with virus or other plant poisons."

Basic entomological research is of value to other basic research, particularly biological research. Much of the work has only a remote connection with agriculture, but it supplies data on the action of insecticides, the development of resistance to insecticides, the nature of insect disease, and so forth.

Plant Genetics

The use of radioisotopes in genetics research will have significant economic benefits that cannot be evaluated now because of the time that is necessary for their value to be realized.

Four years after Becquerel’s discovery of natural radioisotopes, in 1900 the science of genetics took form, but it was not until 1927-28 that proof of mutation from radiation was reported. Development of radiation genetics has been slow because geneticists were so impressed by
the destructive effects of radiation. Fortunately, this view was changed when Swedish research workers reasoned that a small part of the radiation induced changes might be useful in breeding improved crop varieties. Today with the encouragement of the Atomic Energy program, the interest in the use of radioisotopes is strong.

Using radioisotope tracer techniques, scientists are acquiring new knowledge of the basic workings of the cell that they could not acquire with even the best micro-chemical techniques. The radioisotopes P^{32}, S^{35}, H^{3}, Ca^{45}, and Fe^{59} have been of importance to studies on gene functions, chromosome reduplication, and of the localization of certain elements in the cell. These studies form a basis for understanding genetic mechanisms that is a foundation for the whole field of genetics, cytology, and mutation research. "A more thorough study of interrelationships between mutants and their biochemical blocks may help to accelerate progress on the problems concerned with photosynthesis."

Radioisotopes have been applied internally and externally to produce mutations. The work using them internally was stopped before any conclusive data were obtained.

During the process of selecting beneficial characteristics, many mutations without them must be discarded. Because of this discard, animal mutations induced by radiation are too costly for extensive experimental work at present. The exception is mutation of poultry. Plants which are much less expensive can produce practical mutations if efficient treatment is used.

There are several radiation methods for inducing mutations in plants. Progress in the improvement of efficiency of radiation as a mutagenic agent is shown by the different techniques developed for pre- and post-irradiation treatment with different levels of ionization density. Tests showed that a low level ion density was preferred as it aided in the effectiveness of pre- and post-treatments. Mass screening techniques have also increased efficiency by isolating mutants from large populations of treated material.

A number of economically important mutations have been induced by irradiation. Among them are: disease resistant barley, oats, and wheat; barley, oats, wheat, rice, and flax with stiffer and shorter straw; barley, oats, wheat, peanuts, peas, sesame, and oil mustard with higher yields; and earlier or later maturing barley, oats, wheat, and soybeans.

Known plant forms fall prey to new forms of pathogens each year. This reduces the number of known genes that are useful to a plant breeder.
Radiation can produce more varieties of a crop in one season than would otherwise be expected in a lifetime. Irradiation induced mutations will help the plant breeder meet the threat of new pathogens by producing new disease resistant varieties. Mutation techniques to accomplish this task have not been perfected but offer great promise.

Study of radiation induced mutations is useful in basic research in genetic mapping of chromosomes, mechanism of genetic action, the nature of host-parasite relationship, physiological processes, and the nature, organization, and relationships of genes. Chromosomal translocation can make it possible to transfer genes from wild plant forms to cultivated species.

The available evidence shows only a small part of the probable potential return to be gained from the applications of radiation in genetic research.

Plant Physiology

The advent of nuclear energy has greatly assisted the plant breeder in the development of new plant forms. The use of radioisotopes has increased the naturally occurring mutation rate by several thousands. Development of mutation techniques using radioisotopes allows the breeder to produce new plant forms with improved production characteristics—plants with more food value and higher yield, plants that are adapted to various soil conditions and mechanical harvesting, plants that are resistant to disease, and plants with improved esthetic properties such as richer color or firmer texture. Over 60 different crop plants have been studied using radioisotope techniques. Twenty years ago, 70 percent of the seeds grown today were unknown.

An understanding of photosynthesis, the basis of life on this earth, is one of science's important goals. The use of radioisotope techniques in agricultural research has not only advanced understanding of the process but also made it possible to increase the efficiency of many contributing factors—optimal time and placement of water and fertilizer for example. The study of alkaloid synthesis has developed information on the optimal time for harvesting.

Using radioisotope tracer techniques, fertilizer and soil studies have helped to determine different plant requirements under various conditions. An appreciable extension of the short growing season in the northern states can be affected by counteracting low soil temperatures
with heavy fertilizer application. Knowledge of the proper kind, amount, and placement of fertilizer for different plants under various conditions has developed new practices in root and foliar feeding.

Study of the mode of entry, distribution, and action of plant regulators has developed information used to prevent preharvest drop of fruit and to control flowering and fruiting. Pineapple production has been placed on an assembly line basis with fields ripening in succession as desired.

Radioisotopes have been useful in the study of plant diseases and weeds. Knowledge of root distribution, the occurrence of natural root grafts, and insect movement and activity have been helpful in controlling the spread of plant disease. Herbicides, one of the recent important discoveries of agriculture, have been developed with the help of tracer techniques. Agricultural losses due to insects, diseases, and weeds are estimated to total $11 billion per year.

The beneficial and detrimental effects of water on plants have been studied by the use of radioisotope tracer techniques--lakes have even been stirred up to study the circulation of their nutrient elements. Knowledge of the source of water, necessary to plant life, is helpful in estimating water supply, its depletion and replenishment, and its relationship to drought. Detrimental effects of water are found in leaching of plant nutrients by prolonged rain or rain occurring at an unfortunate time.

Soil Sciences and Water

Agricultural production is dependent on soil for the material in which plants imbed their roots, the source of elements which are essential to plant growth, and the medium in which artificially added elements--fertilizer--are stored. Agricultural production is dependent on water for the source of elements which are essential to plant growth and the solvent which brings the soil's essential elements into solution, the form in which plants can utilize them.

With one important exception, soil and water effects in agriculture are closely related. This exception is the total amount of water available for crop production. Ease and accuracy of estimating total water supply has been greatly facilitated by the use of radioisotope techniques to measure the depth and density of mountain snow packs, to study the flow of underground waters, and to measure water table levels.
Knowledge of total water supply is useful in planning irrigation allocation and schedules, acreage to be planted, and the type of crops.

Soil temperature, aeration, and moisture and soil's physical restriction on root growth are all important factors in agricultural production. Radioisotope methodology for measuring these physical properties is being investigated with some success particularly in the measurement of soil moisture. This is soil's most important physical property for agricultural purposes. Its accurate and easy measurement will allow the farm operator to make the most efficient possible use of the water available.

The use of radioisotopes in soil research has had its greatest success in connection with the chemical properties of soil which govern amount and availability of nutrients to growing plants. In the laboratory, greenhouse, and field, the accuracy and ease of estimating the amount of certain essential elements, particularly P, Ca, S, and K, available to growing crops have been advanced by the use of radioisotope methodology. Radioisotope research has produced information that has shown where fertilizers should be placed, what time in the growing cycle they should be applied, the age at which the plant absorbs the greatest quantity, and how much leaching or movement may take place in the soil after application.

Soil-borne micro-flora and fauna affect agricultural production, some beneficially, but most, harmfully as they carry disease. Radiation offers a possible means of destroying the harmful ones, but practical methods for this purpose have not yet been developed.

The economic benefits resulting from the use of radioisotopes in soil and water research are difficult to estimate. Reduction of the phosphate fertilizer bill by 10 percent would result in an annual savings of $15 million.
Appendix A

CONSULTANTS' REPORTS ON CURRENT AND POSSIBLE FUTURE APPLICATIONS OF RADIOISOTOPES
Introduction

Radioisotope methodology has attained widespread acceptance by agricultural scientists as a most valuable tool in basic and applied research. Investigators are now fully aware of the many advantages that are offered by the proper use of isotope techniques in physiological, nutritional, toxicological, and diagnostic studies with farm animals. As more radioisotope training courses are made available to members of the state and federal agricultural establishments, an increase in radioisotope application to problems of agriculture can be expected. Radioisotope detecting equipment is now available, is relatively inexpensive, and the cost of most isotopes would not be financially limiting, certainly when the liberal fiscal policy of the United States Atomic Energy Commission in the sale of isotopes to agricultural workers is considered. It would seem, then, that isotope usage would depend primarily on the specific problem at hand and the imagination and awareness of the researcher.

Two important properties of radioisotopes make them particularly valuable; these are their ease of measurement with appropriate equipment, and the extreme sensitivity of detection. Another significant consideration is that most radioisotopes behave as do their nonradioactive, stable counterpart; for example, no differences in the metabolism of radio-calcium (Ca$^{45}$) and normally occurring calcium (Ca$^{40}$) have been found. Therefore, by tracing the metabolism of Ca$^{45}$ in the body and by correctly interpreting data, the metabolism of body calcium can be elucidated.

Valuable information using isotopes has already been forthcoming in the animal sciences as can be evidenced by a cursory examination of the technical literature. Appended to this report are some 150 references of recent papers on the use of radioisotopes in animal husbandry; this should give the reader an indication of the scope of the application already made with this research tool. Also included in this report are descriptive examples of the profitable manner in which radioisotopes have been employed and are continuing to be used. It should be mentioned that these illustrative studies recorded here were drawn mainly from investigations carried on at Cornell University, University of Tennessee--Atomic Energy Agriculture Research Program, Michigan State University, University
of Missouri, University of California (Davis), Western Reserve University, University of Massachusetts, and the University of Maryland, as well as numerous other agricultural experiment stations in this country and abroad.

Even though many possible radioisotope methods now in routine or research use by the medical profession or in laboratory investigations with small animals have not been fully carried over to the animal husbandry or veterinary field, a section has been included to summarize such potential applications. Here the methods have been classified according to type of radioisotope and whether the technique will find usefulness on a routine basis or primarily in more basic research. It should not be implied, however, that all applications of radioisotopes in the agricultural sciences have originated and have been carried over from other disciplines. On the contrary, significant research methodology has moved in the opposite direction from agriculture to the other biological sciences.

Lastly, a section has been included to indicate the possible economic potential and impact of atomic energy on the livestock industry. The primary approach has been to examine nutritional and infectious disease states in farm animals already known to contribute significantly to losses in production or dollar value and to select those where radioisotope methodology may be used to advantage. Mention has also been made of a few areas wherein an economic benefit has already been realized. However, an estimation of the contribution of a given technique to any economic saving or enhanced production is difficult and obviously wrought with hazards.

Current Applications of Radioisotopes in Farm Animals

Skeletal physiology. In recent years, the radioisotopic counterparts of bone mineral constituents, in particular Ca$^{45}$ and P$^{32}$, have continued in usefulness for the study of skeletal physiology and metabolism. More sophisticated techniques for measuring skeletal growth and resorption have evolved and have been applied to farm animals. These methods will enhance our basic knowledge in this area and also provide a valuable tool of practical implication.

The bone increases in length and width during the growth phase of the animal. This growth is the net result of two processes—(1) accretion or total bone growth and (2) resorption or the continuing dissolution of bone. Total bone growth (accretion) was not measurable with any degree of accuracy prior to the availability of isotopes and prior to the perfection of appropriate techniques. The study of total bone growth with tracers has certain advantages and these are listed as follows: (a) the
rates of bone salt formation and resorption can be readily determined with considerable sensitivity over relatively short time periods, (b) the effects of disease states, dietary regimes and other factors on skeletal accretion can be delineated from effects on resorption, (c) further insight into mechanisms may be forthcoming, (d) the results reflect changes in the total skeleton, (e) the data are obtainable without sacrificing the experimental animal and the same animal can be used in consecutive studies.

There are two general isotopic methods for determining total bone growth. One technique is to follow the fate of a single intravenously injected dose of Ca$^{45}$ and the rate of deposition in the skeleton. The second approach is to feed Ca$^{45}$ with the diet over a number of days and determine the skeletal retention of Ca$^{45}$ as well as the amount of ingested radio-calcium and radio-strontium. Total bone growth is estimated by a mathematical analysis of these data. By such methods, the rate of skeletal accretion in cattle, sheep, and lactating and nonlactating goats have been calculated. It was found, for example, that the total skeletal growth of mature ruminants of several species was about the same when expressed on a per kilogram of body calcium, i.e. about 3-5 gram of calcium per day. The accretion rate of calves and lambs about 0.3 to 0.5 months was about eight fold greater than that of the mature individuals.

An autoradiographic technique for measuring net bone growth has been employed to excellent advantage in nutritional and toxicological studies. The growing animal is injected with Ca$^{45}$ after having consumed the experimental diet for a number of days. At about two weeks after the injection of the isotope, a long bone is excised at autopsy and an autoradiograph prepared from a longitudinal section. The distribution of the radioactivity in the bone sections can thus be visualized on photographic film. Calcium-45, immediately after injection, deposits primarily in the region of rapid skeletal growth—the epiphysis. As growth occurs thereafter, the new bone that is laid down causes a separation of the previously deposited radioactivity into two distinct bands; the distance between these bands is a function of the amount of bone growth that occurred since the radio-calcium was given. The autoradiographic method has proven to be a sensitive, precise, and accurate technique for measuring the growth of long bones. From observations of this nature, the effect of various levels of fluorine on bone growth was determined and a better understanding of fluorine toxicity was attained. Also, an estimation of the phosphorus requirements of dairy calves was recently accomplished with this technique. From these studies, it was determined that the minimum phosphorus requirements of calves weighing, on the average, about 240 lbs at 12 to 18 weeks of age were approximately 0.22 percent of the air-dried ration. Since the present feeding standard for such animals is
as high as 0.40 percent phosphorus in the diet, the feeding recommenda-
tion could be safely scaled downward to about 0.30 percent phosphorus. This method could profitably be extended to other nutrients for estimat-
ing requirements as well as influence on bone growth.

Functional status of the thyroid gland. The radioisotope that is most used in agricultural experiments is $^{131}$I. This isotope is almost completely sequestered in the thyroid gland and built into the hormones of that gland, thyroxine and triiodothyronine. The interest in thyroid metabolism stems from the control that this gland exerts upon such physiological processes such as reproduction, milk secretion, egg laying, wool production, growth, and fattening. The study of the thyroid has been greatly aided by the production of large amounts of inexpensive, very pure, easily measured radioiodine. Its usage has allowed scientists to observe the dynamic changes in blood iodine when injected in the inorganic form, the gradual reduction of $^{131}$I in the blood as it is accumulated by the thyroid, the time changes in its conversion to thyroxine and triiodothyronine, and the release of thyroxine-$^{131}$I by the gland back into the blood. The pathways of excretion of organic and inorganic $^{131}$I in the urine, feces, placenta, and milk have been studied. The problems of the metabolism of thyroxine involving deiodination and deamination and the recycling or reutilization of $^{131}$I have also received attention.

In particular, the work at Missouri has been carried out with the premise that the productivity of farm animals might possibly be correlated with the functioning of the thyroid gland. By determining the activity of the thyroid gland of individual animals we could accelerate the development of a group of animals adapted to produce well under the particular environmental, nutritional, or physiological conditions with which we have to contend.

Since the important function of the thyroid is to secrete thyroxine, some measure of this ability would be desirable for correlation with a particular production characteristic. The uptake or release of $^{131}$I by the thyroid was shown to be an unreliable index and so attempts were made to measure the secretion of labeled thyroxine. The procedure depends upon the fact that the thyroid-stimulating-hormone of the pituitary actually controls the secretion of thyroxine. Also, the level of thyroxine in the blood in turn regulates the production of the pituitary hormone. To measure thyroxine secretion, the animal is given an intravenous injection of $^{131}$I and, after a period of 1 to 3 days, is given a goiter-producing chemical in its diet. This prevents the thyroid from picking up any $^{131}$I that might be circulating in the blood and the release of radioiodine from the thyroid can be estimated. Then known amounts of thyroxine are
injected so as to reduce the production of the thyroid-stimulating hormone and thus reduce the rate of thyroxine secretion by the thyroid. The lowest level of ingested thyroxine capable of preventing the loss of I\textsuperscript{131} by the thyroid gland is considered as the amount of thyroxine that the animal normally secretes in a day. These values have been obtained for beef and dairy cows, sheep, and chickens. The secretion of thyroxine has been found to be at a lower level in low producing milk-cows and chickens than in high producers. With cows it has been shown that three times as much thyroxine is secreted in the winter as in the summer, due mainly to temperature changes. However, those animals demonstrating an ability to produce well during hot weather showed only small decreases in their thyroxine secretion rate.

More fundamental studies of this nature must be carried on if we are to better control or to alter the thyroid state for practical advantage in animal production.

Isotope dilution techniques for body water and other volume measurements. In agricultural research, especially that dealing with nutritional problems, it is frequently necessary to know the total amount of water in the body, or "water space," of living animals. Radioactive hydrogen or "tritium" in the form of tritiated water is especially advantageous for these determinations since its distribution is uniform throughout the water space of the whole organism. For the analysis it is only necessary to know the amount of tritiated water injected and the ratio of tritiated water to ordinary water in the blood after equilibration. From these values it is possible to estimate the amount of body water in the animal at the beginning of the experiment and as influenced by the experimental conditions. In such a study, however, it was noted that the tritium entered into the water of the digestive tract as well as that of the tissues. This could lead to erroneous results, especially in ruminants because of the variable amounts of water in the rumen. It was also noted that N-acetyl-4-amino-antipyrene did not pass into the gut but did distribute in the water of the body proper. By injecting both tritiated water and the N-acetyl-4-amino-antipyrene, it was possible to estimate the water in the entire animal, the water contained in the digestive tract and, by difference, the water in the body proper. From such knowledge it is possible to calculate the amount of fat and protein in the animal body and the calorie content of such tissue. These values in turn can be related to the efficiency of feed utilization as affected by diet, inheritance, or environment.

Blood volume measurements are similar in principle to measurement of the body water. An essential difference is that precautions must be taken
to prevent the radioisotope from escaping from the circulatory system and thus giving an erroneously high volume. To achieve this, the radioisotope (Fe$^{59}$, Cr$^{51}$, K$^{42}$, P$^{32}$, or I$^{131}$) is combined with some cell or other material which is a natural component of the blood and which ordinarily does not diffuse out of the system. Most often the red blood cells are labeled outside the body and then injected back into the body; the dilution occurring enables one to calculate the red cell volume of the entire body. Albumen is frequently labeled with radiiodine and upon injection and dilution enables the estimation of the plasma volume of the body. The total blood volume would, of course, equal the sum of the plasma and red blood cell volumes. Using such techniques the blood volumes of the various farm animals have been estimated by several workers. These values are important because of the possibility of evaluating changes in body fluid volumes caused by nutritional, physiological, or pathological disturbances such as pregnancy, lactation, obesity, shock, renal diseases, thyroid diseases, and others.

Studies of biochemical synthesis with radiocarbon and tritium. Radioisotope and labeling techniques have proven indispensable in the determination of precursor-product relationships in biochemical and physiological synthesis. The isotopes of particular usefulness here are carbon-14, tritium, deuterium, nitrogen-14, and sulfur-35.

Much attention has been given recently to the formation of galactose and lactose by the mammary gland of the ruminant. Studies have been carried out with the intact mammary gland, the isolated mammary gland maintained by perfusion slices of mammary tissue and with homogenates. Previous investigations have been hindered not only by a lack of a practical method for tracing the movement of an organic molecule or molecular fragment through various stages of synthesis but also by a lack of a specific and sensitive method for the determination of lactose; the availability of carbon-14 has remedied to a large degree both situations. Much progress has recently been made in this area. For example, it has been observed that 80 percent of the C-14 intravenously injected as glucose in the intact cow is incorporated into lactose. Although labeled carbon of glucose is largely found in the lactose molecule, glucose is also utilized for the synthesis of other milk constituents as evidenced by the appearance of some C$^{14}$ in casein and milk fat.

A profitable technique that has been used to advantage has been the injection of labeled compounds into the pudic artery that directly feeds the mammary gland. In this way it is possible to use one half of the udder for control purposes, inasmuch as there is a rapid removal of metabolites from the blood during one cycle through the mammary gland. When
acetate-1-C\textsuperscript{14} was injected into the pudic artery, it was found that there was an unequal and unsymmetrical labeling of the glucose and galactose portions of lactose. Galactose was more highly labeled than glucose. This was similar to the observations obtained from mammary perfusion studies. Contrariwise, when acetate-1-C\textsuperscript{14} was injected into the jugular vein of the intact cow, or the C\textsuperscript{14} distribution in lactose of the non-injected side of the udder was determined, it was found that the amounts of label in glucose and galactose were equal. Likewise, glycerol-1,3-C\textsuperscript{14} placed in the pudic artery resulted in a greater amount of labeling in the galactose portion of the milk sugar. Thus it was apparent that within the mammary gland, glycerol and acetate preferentially label the galactose portion of lactose. From these and other observations, several possible mechanisms have been suggested for the course of lactose synthesis, especially in reference to the source of carbon for the glucose moiety and the galactose moiety of the disaccharide molecule.

In other studies, the observation has been made that glucose-6-C\textsuperscript{14} contributes more isotope to the amino acids, alanine and serine of casein, and to the glycerol of milk fat than does glucose-1-C\textsuperscript{14}. From these results it was estimated that one-half to two-thirds of the glucose is catabolized via the pentose cycle in the lactating cow. Also by following the specific activity of the C\textsuperscript{14} in the fatty acids, glycerol, lactose and serine of milk formed after the injection of glycerol-1,3-C\textsuperscript{14} in the pudic artery, it was proposed that there exists in the mammary gland different secretory processes for fat and for lactose and casein.

The highlights of recent studies with C\textsuperscript{14} just presented illustrate the usefulness of this isotope in such investigations. Radiocarbon has been advantageously employed elsewhere in animal physiology for the elucidation of basic mechanisms of synthesis and catabolism. Examples of other applications are the use of C\textsuperscript{14} labeled glycine in the measurement of serum protein turnover rates in dairy cows, the effect of penicillin on the absorption of radiolysine, the nature of incorporation of C\textsuperscript{14}-labeled amino acids in the oviduct tissue of the hen, the metabolism of C\textsuperscript{14} labeled hormones in cattle the specific oxidation and utilization of C\textsuperscript{14} labeled acetate and glucose in various species, dietary factors influencing the metabolism of C\textsuperscript{14} labeled cholesterol in chickens and in investigation of the metabolism of the rumen microflora.

Although few studies with tritium (H\textsuperscript{3}) have been performed in farm animals, one may expect its increasing use, taking advantage of the desirable characteristics of this label. Compounds that cannot be synthesized in the chemical laboratory or only with great difficulty may be labeled by the Wilzbach technique. Exposure of the molecule to tritium gas under the appropriate conditions will cause the tritium to replace
normal hydrogen (H\(^1\)) atoms in the molecule. Although there are several drawbacks to this method, a far greater number of biologically significant compounds will be isotopically labeled than would be labeled otherwise. In addition, the commercial availability of liquid scintillation detectors for measuring H\(^3\) and C\(^{14}\) should provide an additional impetus for such studies.

**Miscellaneous uses of radioisotopes.** Studies of inorganic elements in addition to iodine, calcium, and phosphorus offer much promise in agricultural research and are especially amenable to the use of radioactive isotopes; the results encourage their use in many areas.

Radioactive sulfur (S\(^{35}\)) is a radioisotope of considerable interest since this element is a component of several amino acids and therefore can be used to observe patterns of protein synthesis and some detoxication mechanisms of the body. Chickens, pigs, sheep, and cattle have been given radiosulfur in the form of sulfate and have been observed to incorporate it into the many proteins of the body and the mucopolysaccharides of teeth and skeleton. Since the proteins of milk, hair, hides, feathers, and eggs are rich in sulfur, these results are of interest and indicate that inorganic forms of sulfur can be used to supply some of the sulfur requirement. Labeling of proteins and mucopolysaccharides with sulfur-35 has made it possible to study the effect of the hormones, such as cortisone, and vitamins, such as vitamin D, upon the turnover of these materials.

The ability of rumen bacteria to utilize many inorganic forms of sulfur to form sulfur-containing amino acids has explained why ruminant animals are less critical than nonruminants in their needs for certain amino acids. The amino acids formed have been shown to be available for such functions as hair, wool, milk, and meat production.

A rather unique use has been demonstrated for the naturally occurring radioisotope of potassium. Since potassium is found within the cell and in greater amount in muscle than fat cells, the radiopotassium content of the tissue has been used to determine the fat-free lean meat content of hams. Since attempts are being made to produce pork with a smaller fat to meat ratio, such an analysis on a live animal could be of extreme help in a breeding and nutritional program.

The metabolism of fluorine, sodium, potassium, and iron have been investigated to some extent in cattle, sheep, goats, and swine but a good deal remains to be done. Radiiodine has been used to determine if goiterogenic substances fed to livestock can be carried over to the consumer. Also, radiochromium is fed in the nonabsorbable form of chromic oxide to
serve as a standard so that the digestibility of any component of the diet can be determined. Similar studies have been accomplished with radiocalcium or radiophosphorus to determine the availability of many kinds of calcium or phosphorus supplements fed to farm animals. A rather unique use is the administration of radiocalcium to a pheasant hen so that the chicks hatched from eggs of this particular hen can be readily recognized.

Metabolism of fission products. The advent of nuclear energy in its various forms has necessitated a type of research that is relatively new to agriculture and extremely important. This is the study of the metabolism of fission products by farm animals. At present, nuclear tests constitute the main source of contamination of the biosphere with the fission products. For understanding and a better evaluation of the potential hazard, it is necessary to study in detail the metabolism and movement of fission products in the food chain. The understanding of the movement and behavior of extraneous radioactive materials in the food chain requires an integration and application of existing knowledge of agricultural practices.

A particularly active area of research is the metabolism of radioactive strontium by dairy cows and dairy goats. These studies are important since it has been estimated that from 70 to 80 percent of the calcium of the diet of the population of the United States comes from dairy products. The cow and the goat have been shown to discriminate against strontium in favor of calcium as these elements pass from diet to milk. Thus, the calcium of milk contains only one-tenth of the strontium that it contained while in the plant. The dairy cow in this way serves as a sort of a filter to protect the human population. The discrimination mechanism has been found to exist in the intestinal tract and in the kidney. Active research is now under way in an attempt to increase the degree of selection at these sites.

The studies employing radioactive iodine, while having other purposes as their main goal, serve to give information about the metabolism of iodine that is useful in evaluating the hazards of fall-out radiiodine. The absorption, distribution, and excretion of iodine-131 has been charted for fetal and adult sheep, dairy cows, and swine. In addition, the effect of stable iodide on the thyroid accumulation of radiiodine has been investigated.

Other fission products such as cesium, tellurium, ruthenium, and barium have also been administered to farm animals to determine their metabolic fate. Work is continuing in this field with a particular point
of view of determining levels that constitute a hazard to the population and ways of reducing these hazards.

Future Uses of Radioisotopes in Farm Animals

The full research potential of radioisotope studies in farm animals has not been realized to date. This is partly due to the relative high cost of such research in large animals, the problem of disposal of contaminated carcasses, the possibility of cross-contamination of isotopes to animals raised for slaughter, i.e., limited facilities, and inability to salvage any value from the carcass with certain isotopes. A recent memorandum published by the Meat Inspection Division of the U.S. Dept. of Agriculture indicates a more liberal policy of that department on the sale of meat for human consumption from animals that have received radioisotopes. This memorandum, issued March 10, 1959, is of such importance as an indication of the present attitudes toward radioisotope application in farm animal research that it is quoted here in its entirety:

"Meat from animals which have been treated with radioactive isotopes for experimental purposes will be considered wholesome and eligible to receive the marks of inspection, if otherwise acceptable, under the following conditions:

"If the radioactive material is not retained in the treated animal; or in the case of retained material, when decay of radioactivity of the residue has reduced the level of radiation to essentially that of normal background. The determination that essentially background radioactivity has been reached shall be made by a count on an ashed sample using an instrument capable of detecting activity 10 percent above the background of a similar sample from a control animal, to be measured in the same manner. Each organ and tissue such as muscle and bone intended to be used for food shall be separately tested in a like manner.

"It is contemplated that the agency which conducts the experimentation will be equipped to conduct the tests. Certification concerning the results of the tests shall be made by the agency to the appropriate inspector in charge of Meat Inspection. In any case, the inspector in charge shall report in detail to this office."

Some of the possible applications of radioisotopes in this area have been summarized and presented herein in tabular form. The various
uses are listed under the respective isotopes and the applications have been further categorized according to whether the particular isotope and technique is more likely to be employed routinely or primarily as a research tool. This table is far from complete but should further indicate the extensive and diverse manner in which isotopes can be advantageously used. Elements other than those listed may be of interest only from the point of view of toxicity since they are not commonly found in feedstuffs but may appear only in pharmaceutical preparations. The absorption, distribution, and excretion of these materials by farm animals is therefore of importance. Examples of these are antimony, arsenic, barium, beryllium, bismuth, bromine, cadmium, mercury, nickel, and silver.

Tabulation of Current and Expected Uses of Isotopes in Farm Animals

I. Calcium-45

A. Research Use

1. Estimation of bone accretion and resorption; influence of hormones, nutrition, exercise, and physiological status.

2. Study of formation of teeth.

3. Determination of the availability of calcium of feedstuffs.

4. Study of the etiology of diseases such as milk fever, grass tetany, hypomagnesia, rickets, cage-layer fatigue, gallstones, and urinary calculi.

5. Study of milk and egg formation; placental transfer.


7. Determination of endogenous calcium as influenced by diet, hormones, and other physiological factors.

8. Estimation calcium requirement for various species.

B. Routine Use

1. Estimation of the vitamin D content of feeds by a chick or rat assay procedure.

2. Determination of endogenous calcium in individual animals.

II. Phosphorus-32

A. Research Use

1. Estimation of bone accretion and resorption; influence of hormones, nutrition, exercise, and physiological status.

2. Study of formation of teeth.

3. Study of milk and egg formation; placental transfer.


5. Study of the absorption of phosphorus in the digestive tract, the mechanisms and form in which it is absorbed, and factors which enhance or reduce utilization.

6. Estimation of endogenous phosphorus as affected by diet, hormones, and physiological factors. Also, the relative contribution of the various phosphorus compounds in the blood and cells of the intestinal tract to the endogenous phosphorus.

7. Study of the excretory function of the kidney.

8. Investigation of the formation, turnover, and precursors of the organic phosphorus compounds of bones and soft tissues.

B. Routine Use

1. Determining adequacy of blood supply to a fractured bone.

2. Use of therapeutic levels for treating polycythemia.

3. Use of colloidal phosphate impregnated sutures to prevent neuromas from developing after neurectomy in horses and other stock.

4. Assay of feeds for vitamin D content using chicks or rats.

5. Irradiation of skin tumors and other tumors that accumulate phosphorus.

III. Strontium-85 and Strontium-89

A. Research Use

1. Contrasted to Ca^{45} to provide a basic understanding of the various selective mechanisms of the body.

2. Useful as a substitute for calcium-45 in studies of a qualitative nature.

B. Routine Use

1. Substitute for calcium-45 for vitamin D assays.

2. Determination of whether or not a bone fracture is healing properly.

3. Determination of bone accretion or resorption rates in farm animals by external counting.

4. Irradiation of localized tumors.
IV. Carbon-14

A. Research Use

1. Study of the metabolic contributions of bacteria, yeast, and protozoa to the nutrition of ruminants and nonruminants. The synthetic, as well as catabolic, products and mechanisms can be investigated.

2. Study of the metabolism and distribution of fats, proteins, and carbohydrates within the animal body and the utilization of these for production.

3. Estimation of rates and mechanisms of absorption of materials from various parts of the digestive tract.

4. Investigation of the mechanism of action of materials such as vitamins, hormones, antibiotics, and other drugs.

5. Determination of residual levels and utilization of food additives.

6. Study of the utilization of various carbon sources by animal tissue.

7. Study of excretory mechanisms of the kidney.

8. Study of detoxification mechanisms.

9. Investigation of movement of labeled viruses or bacteria.

B. Routine Use

1. Determination of residual levels and utilization of food additives.

2. The use as a criterion for the toxicological effects of new drugs.
V. Sulfur-35

A. Research Use

1. Study of utilization of various forms of inorganic and organic sulfur by animals.

2. Study of the formation of amino acids, proteins, and mucopolysaccharides by the body and their subsequent utilization for reproduction, growth, milk production, egg formation, and hair production.

3. Investigation of kidney excretory functions.

4. Study of the detoxification mechanisms involving sulfur.

5. Determination of the sulfur requirement of farm animals.


7. Study of diseases by use of labeled pathogens.

B. Routine Use

1. Determination of the "extra cellular space" ("sulfate space").

VI. Iodine-131

A. Research Use

1. Determination of thyroid function and correlation with desirable production characteristics of farm animals.

2. Use as an aid to selective breeding in regard to a desirable level of thyroid function.

3. Study of absorption and metabolism of fats in the animal body.

5. Study of thyrotoxicosis.

6. Estimation of the utilization of iodine from various feed sources.

7. Study of the metabolism of iodine by all farm animals.

8. Determination, with more precision, of the iodine requirement of farm animals.

B. Routine Use

1. Determination of thyroid uptake and basal metabolic rate.

2. Estimation of rate of formation of thyroxine.

3. External scanning for thyroid tumors.

4. Determination of plasma volume with I$^{131}$ labeled albumen.

5. Determination of liver function with I$^{131}$ Rose Bengal.


7. Application for partial or complete destruction of thyroid gland with massive levels of radioiodine.

8. Determination of the absorption of fats in steatorrhea.

9. Application in kidney function test--I$^{131}$ labeled diodrast.

VII. Iron-59

A. Research Use

1. Estimation of the iron requirement of farm animals as related to age, sex, nutrition, disease, and hormone status.
2. Determination of the availability of iron from various sources and forms.

3. Study of the absorption, storage, and utilization of iron.

4. Estimation of blood volume of farm animals and the effect of various factors thereon.

5. Study of hemoglobin and enzyme formation.

B. Routine Use

1. Determination of iron turnover rates.

2. Determination of blood volumes.

3. Estimation of iron uptake by red blood cells.

VIII. Copper-64

A. Research Use

1. Study of the distribution, absorption, and excretion of copper as influenced by age, sex, nutrition, disease, and other physiological conditions.

2. Study of the function of copper in hemoglobin and enzyme formation.

3. Investigation of the function of copper in the body.

4. Estimation of the availability of copper from various sources.

5. Study of the toxicity of copper.

B. Routine Use

1. Localization of tumors.
IX. Chlorine-36

A. Research Use

1. Study of the absorption, distribution, and excretion as related to the cationic component and the nutritional and physiological status of the animal.

2. Study of acid-base balance, osmotic balance, and kidney excretion in animals.

3. Determination of the "chloride space."

X. Cobalt-57-58, 60

A. Research Use

1. Study of the absorption, distribution, and excretion of cobalt as influenced by chemical form and the nutritional and physiological status of farm animals.

2. Estimation of the utilization of cobalt by bacteria to form vitamin $B_{12}$ or $B_{12}$-like substances.

3. Study of the absorption, distribution, and excretion of vitamin $B_{12}$.

4. Determination of the mode and site of action of $B_{12}$.

5. Estimation of cobalt and $B_{12}$ requirement of farm animals.


B. Routine Use

1. Irradiation of tumors.

2. Determination of efficiency of gastrointestinal absorption of radioactive vitamin $B_{12}$.

3. Clinical test for pernicious anemia.
XI. Tritium

A. Research Use

1. Study the movement and metabolism of many organic compounds and their utilization in milk, egg, or meat formation.

2. Study of the metabolism of rumen or digestive tract organisms to determine their metabolic contribution to the host.

B. Routine Use

1. Determination of residual levels and utilization of food additives.

XII. Manganese-52, 54

A. Research Use

1. Study of the absorption, distribution, and excretion of the various forms of manganese; can be studied in respect to the effect of various nutritional and physiological states of farm animals.

2. Determination of the function of manganese in bone formation.

3. Study of the function of manganese in enzyme systems in the body.

4. Estimation of the minimum requirement of manganese and the effects of toxic levels.

XIII. Potassium-40, 42

A. Research Use

1. Study of the factors controlling the preferential sequestering of potassium by the cells.
2. Investigation of the absorption, distribution, and excretion of potassium as affected by nutrition of and physiological changes.


4. Determination of the mechanism of potassium excretion by the kidney.

5. Estimation of the requirement for potassium by animals.

B. Routine Use

1. Determination of the "potassium space" of the body.

XIV. Magnesium-28

A. Research Use

1. Study of the absorption, distribution, and excretion of magnesium.

2. Investigation of the function of magnesium in various enzyme systems.

3. Determination of the minimum requirement of magnesium by animals.

4. Study of the interrelationship between calcium and magnesium.

5. Study of kidney excretion mechanisms.

XV. Sodium-22, 24

A. Research Use

1. Study of the function of sodium in acid-base balance with particular regard to the kidney.

2. Study of the secretion of HCl by the stomach.
3. Study of the relative exclusion of sodium from the interior of cells.

4. Determination of the space into which sodium will penetrate in farm animals and the relation of this to various nutritional and physiological conditions.


6. Investigation of kidney function and excretion.

B. Routine Use

1. Determination of the "sodium space" of the body.

XVI. Zinc-65

A. Research Use

1. Study of zinc metabolism; the effect of nutrition and physiological status.

2. Investigations of the function of zinc in enzyme systems.

3. Determination of the effect of high calcium diets upon zinc absorption.

4. Estimation of the excretion of zinc, particularly by the kidney.

5. Study on the toxicity of zinc.

Speculations on the Potential Economic Benefits of Atomic Energy to the Livestock Industry

It is now 13 years since isotopes became available for research purposes and only recently have a fair proportion of agricultural research workers begun to use radioisotopes in their experiments. Since large animal experimentation is more difficult to carry out and to replicate, in contrast to studies with small laboratory mammals or with plants, the
full benefit from such investigations have not yet been realized. Also, the long generation time and the delayed productivity of farm animal species make immediate assessment of enlightened farm practice in terms of increased efficiency or enhanced yield quite difficult. However, the greatest contribution of radioisotopes and atomic energy to agriculture is the feasibility of performing experiments that could not be done otherwise. The numerous investigations on the synthesis, turnover, and degradation of components of the animal body by use of C\textsubscript{14} labeled compounds are prime examples of this. Similarly, tritium and sulfur-35 have made possible the tracing of the metabolic fate of hydrogen and sulfur in the body. The measurement of the functioning of the thyroid in the living animal would be impossible without I-131, as would studies on the endogenous excretion of such minerals as calcium, phosphorus, iron, cobalt, magnesium, etc.

Some types of biological research have been avoided in the past because of technical difficulties. With radioisotopes certain types of studies become feasible and so these areas are receiving more attention. Examples of these are the more precise determination of calcium and phosphorus availability in feeds, nutrient utilization by using radiochromic oxide as an indicator in the feed, analysis of certain trace elements by neutron activation, tissue analysis for microelements by feeding the radioisotope of known specific activity until steady state had been reached, blood volume determinations, and estimations of thyroid function. Radioisotopes have made it possible to speed up the number of analysis that a technician can perform in a day and with a precision far exceeding that obtainable by the old methods. Unfortunately, it is impossible to estimate the economic value of such gains since the actual volume of such substitution in research laboratories can never be accurately ascertained.

Speculations, however, on the economic benefits from the application of atomic energy to agricultural problems are possible although, needless to say, such estimations are merely calculated guesses. The areas of benefit would be those dealing with increased production, increased efficiency of production, or decreased losses due to such difficulties as infectious diseases. In the period of 1942 to 1951 the value of all livestock production amounted to approximately 15.7 billions of dollars and the estimable losses were in the order of 2.5 billion dollars. Of the losses approximately 1.5 billion dollars was loss in mortality or production due to various bacterial and viral diseases, another 400 million dollar loss was attributable to the various internal parasites of livestock and poultry while 500 million dollars of losses was caused by insect pests.
It is most likely that radioisotopes will play an important role in reducing these losses in animal production. Many of the causes of agricultural loss have not been amenable to thorough and effective investigation because of the lack of an appropriate research tool. As pointed out before, experiments are now possible that were previously impossible, and the scope of the work can be increased due to the analytical ease provided by radioisotopes. Radioisotopes can fulfill many of these deficiencies and thus facilitate their solution. The tremendous dollar volume of animal products in our economy makes any small contribution toward reduction of losses very significant. Accordingly, this in turn should encourage investigation along these particular lines by investigators who are made aware of the potentialities of research in these particular areas.

The most quoted example is the elimination of the screwworm infestation of the Southland. This pest has cost the livestock industry an estimated 20 million dollars a year in deaths of cattle, permanent injury, and poor weight gains. This does not include the cost of labor necessary to constantly watch and treat the animals during the fly season. By releasing males that have been sterilized by ionizing radiation and being cognizant of the fact that the female screwworm fly mates but once, it has been possible to eradicate completely screwworms from the island of Curacao. It is thought that this could be done as well in Florida and thus free the entire Southeast of this plague. There are certain difficulties, however, since Texas and Mexico in addition to Florida are residual areas of infestation. For effectiveness, the screwworm would have to be eliminated from both the source of the infestation and at the site of difficulty. Possibly, a cooperative program between the United States and Mexico would be warranted in an attempt to eradicate this pest from the North American continent and thus realize the full benefits of such an undertaking.

Nutritional disorders in the livestock industry cause a substantial reduction in animal production; this was estimated to be 5 to 10 percent of the total animal output by the U.S. Department of Agriculture. The major difficulties are mineral deficiencies, mineral excesses, vitamin deficiencies and nutritional imbalances. As indicated earlier, radioisotope methodology has been particularly useful in studying various aspects and interrelationships of the nutritional sciences. With such techniques, a better understanding of the nutritional disease would evolve and, therefore, practical recommendations could be made for alleviating the disease. It would not be unreasonable to assume that eventually one-quarter of the improvement in the nutritional status of farm animals would be due to knowledge gained from isotope application. Thus, since the value of nutritional losses in this country is of the order of 800 million
dollars (1942-1951 figures), a crude estimate of the savings due to radio-isotopes may be about 200 million dollars.

The prolonged season of elevated temperatures in the South has been implicated as contributing to the lower milk production of cows in that area. For instance, in the North, it was noted that short periods of hot weather depressed milk production up to 10 percent; it could be expected that the long periods of very hot weather in the southern states would reduce milk production to a greater degree. Through studies involving $^{131}$, an attempt is being made to correlate thyroid function with the level of production; this information is being used as a basis for selecting heat-tolerant strains of cows for breeding. If this can be done, a considerable saving might result. For example, the "Agricultural Statistics for 1957" lists the milk production of cows in the North Atlantic States as averaging 7,000 lbs each whereas those in the South Central States yielded an average of 3,800 lbs each. If the milk production of the South Central cows is raised only 10 percent by developing heat-resistant milk cows this would mean an increase in production of 380 lbs of milk per cow. At a market price of $4.25 per 100 lbs of milk, the total increase in the dollar value of enhanced milk production for the 13 southern states would be in the order of 65 million dollars a year.

Coccidiosis is a protozoan parasite found in the digestive tracts of chickens, turkeys, sheep, and cattle; the losses from this disease are extensive, particularly in the poultry industry. The disease is difficult to eradicate and the main effort is in the direction of preventative medicine. Little is known about the mechanism whereby the coccidia leave the oocyte and invade the tissues and how the tissues develop a localized immunity to this organism. The use of radioisotopes is strongly suggested to get at these mechanisms. Once basic knowledge has been obtained, treatments can be devised that utilize susceptible points of attack or some means may be found to aid the intestinal tract in developing an immunity against the organism. In the period of 1942-1951 it was estimated that cattle losses from this disease averaged 10 million dollars, sheep about 1 million dollars, and chickens and turkeys about 39 million dollars. If radioisotope research can improve the situation only 20 percent, this would provide a saving of 10 million dollars to the farmer.

Cattle grubs are another group of pests that are an economic scourge to agriculture. Losses include holes in the hides, spoiled areas in the flesh, and loss of weight and milk production among cattle severely attacked by the flies. Losses are estimated to total 100 million (1942-1951) dollars. Recommended treatment consists of applying rotenone or some other safe insecticide on the backs of the cattle and hoping this can destroy the larvae before they emerge; the flies themselves are
relatively resistant to attack. An interesting fact is that the young maggots, after hatching, tunnel through the connective tissues of the host to lodge in the gullet or the spinal canal for several months before moving to the back of the animal. It is during this period that radioisotopes would prove useful in making it possible to determine what compounds, administered to the animal, will be accumulated by the parasites. A thorough knowledge of the metabolic processes of the maggots should then give information about the type of pharmaceuticals that may effectively destroy them. Also, it would be advantageous to use isotopically labeled compounds so that the uptake by the host tissue, and the excretion of the compound in the milk, urine, and feces could be followed and make it possible to assess the danger of the drug itself to the host animal and to the human population. If such research were successful, it might be possible to almost completely eradicate these pests. The savings thus attributable to radioisotopes could optimistically be valued at 30 million of the possible 100 million dollars.

Other internal parasites such as roundworms, flukes, bladder worms, and tapeworms could be investigated in the same fashion as for the grubs. Studies on the uptake of various kinds of labeled compounds can be made while these organisms are parasitizing the host. When enough information is developed it would then be in order to determine the uptake of various toxic compounds by the parasite and the host. This would give far more information than conventional techniques and lead to the development of vermifuges that are toxic to the parasites and nontoxic to the host. These various internal parasites were responsible for about 400 million dollars worth of losses to the animal industry during the period of 1942 to 1951. Much work remains to be done in this field and a reduction of the loss by one half from efforts would be quite significant. Of this 200 million dollars, one may possibly credit 20 million dollars as the direct result of using isotopes as an important research aid in their solution.

Virus diseases take a large toll of the livestock industry and losses of 167 million dollars per year were encountered during the period of 1942 to 1951. Much basic work using $^{14}C$ and $^{32}P$ is now in progress to study the structure of the virus, the mechanism of its attack on cells, and the manner in which it uses the cell's reproductive processes for its own purposes. Much of the work is in the field of human medicine but the results will be equally applicable to agriculture. A conservative estimate of the monetary contribution of this new knowledge in preventing losses by viruses may be of the order of 50 million dollars. These are a few indications of the potential benefits of atomic energy to agriculture.
In summary, the savings to the animal industry are nebulous at present. While a large amount of work has been done and new information uncovered, the utilization of the results on the farm has not yet taken place. The future for radioisotope usage in agriculture is as bright as for other fields of endeavor and, eventually, as food production becomes the most pressing problem facing the world, the contribution of atomic energy to the well-being of human society will be significant.
A Selected Bibliography of Recent Reports on the Application of Radioisotopes in Farm Animal Experimentation


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USES OF RADIOISOTOPES IN AGRICULTURAL ENTOMOLOGY

W. M. Hoskins, Department of Entomology and Parasitology,
University of California, Berkeley, California

The use of radioisotopes in entomology started in 1931 with the feeding of lead arsenate containing Pb\(^{212}\) to silkworms (8) in a study of its absorption and excretion. From this simple beginning with a classical insecticide, radioactive compounds have found increasing use until by now scarcely a segment of the vast science of entomology has not profited from this technique. It probably is natural to think first of radioisotopes in connection with insecticides for they have been indispensable in obtaining an understanding of the processes of absorption, distribution, metabolism, and elimination of these materials within insects, plants, and animals and in gaining at least some understanding of how insects become resistant to a previously effective chemical. But in a larger sense, radioisotopes have facilitated great progress in the normal biochemistry and physiology of insects, upon which the development of better control of pest species is dependent. A large volume would be necessary to cover adequately the researches with radioisotopes in entomology. A number of excellent reviews on various specialized aspects have been published.

It is proposed to limit the present account to what seem to be the more significant lines of research now developing with only essential reference to the background from which they came. For purposes of clarity, division will be made into the following subtopics:

1. Direct effects upon insects of exposure to radioactive elements or their radiations.

2. Uses of radioisotopes in insecticides, including changes in insects, plants, foodstuffs, and soil.

3. Use of radioisotopes in study of the behavior of insects, including rate and extent of dispersal and absorption and discharge of liquids from and into plants.

4. Use of radioisotopes in research on the normal biochemistry of insects.
The important subjects of effects of insecticides upon man and animals, the transmission of diseases to man and animals, insecticides for control of household pests and in food processing will not be covered.

Insects have been subjected experimentally to radiation ever since the discovery of radium and X-rays. Geneticists have been interested in the mutagenic effects and this has become a major tool, as witnessed by the Nobel Award in 1946 to H. J. Muller for his work on artificial mutations in the fruit fly. Since then a vast literature on the subject has accumulated. A parallel development on a much smaller scale has been the use of radiations of various kinds for control of insect pests. The immense losses due to stored products pests, estimated at 10 to 50 percent of the harvest in most regions of the world, have been a challenge since time immemorial. These insects are especially suitable for treatment by radiation because they may be located precisely and handled easily and cheaply. A few examples will illustrate the use being made of radiation for this purpose.

X-rays in sublethal amounts on two flour beetle species, Tribolium confusum and T. castaneum, have little effect on the number of eggs laid but seriously decrease fertility (35). The rice weevil is a very serious pest not only on rice but on many other grains as well. Work in Russia has shown recently that X-rays at 5,000 roentgens applied to grains are close to the minimum sterilizing dose, though 8-10,000 r are recommended for routine use (37). A comparison of X-rays, γ radiation from Co60 and cathode rays from a Van de Graaff accelerator showed little difference in the sensitivity of seven major grain pests at any stage of the life cycle. The particular interest was to develop a practical procedure for sterilizing food packaged for military use. Recommendations were made for use of cathode rays (41).

The most spectacular use of radiation for control of an insect pest is the present effort to eradicate the screwworm from the southeastern United States. This insect, Callitroga hominovorax, is a serious pest on both domestic and wild animals in many parts of the world. The female lays her eggs in wounds on the navel cord of newborn animals or on any abrasion in the skin and the larvae invade not only necrotic but sound tissue. An initial light infestation attracts other females and thousands of larvae may be found in one animal, causing death within a very few days. The annual loss to stock growers has been estimated at ten to twenty-five millions of dollars in the southeastern region alone. In laboratory experiments it was found that both sexes could be sterilized by exposure in the pupal stage to gamma radiation at a dosage of about 5,000 r, the optimum time for application being two or three days before
emergence of the adult flies (30). The emerging males are normally active in fertilizing either irradiated or normal females and the latter lay only infertile eggs.

Research workers and administrators of the United States Department of Agriculture conceived the bold plan of eliminating the screwworm from a selected region by liberating irradiated flies in sufficient numbers to make most of the egg production infertile and thus by stages to eliminate the species. Certain characteristics of the fly are favorable for the plan, e.g., the normal population is very low on comparison with most insects and thus rearing of comparable numbers is not beyond reason; laboratory rearing is fairly simple and may be put on a production basis; the fly may be handled and dispersed as desired without injury; it does not migrate great distances and thus reinfect an area from afar; and, most important, a female accepts only one fertilization (26). By cooperation with the Atomic Energy Commission a Cobalt$^{60}$ source for radiation was set up in Florida and a small island off the west coast was used as an experimental area in 1953. The population was measured by the numbers caught in traps at certain stations and calculations were made of how numbers should decrease with a chosen rate of liberation of irradiated flies. Events proceeded as expected but migration from the nearby mainland prevented a clean-cut eradication.

By arrangement with the Netherlands government a large scale test was made next on the island of Curacao, which is in the Antilles, about 170 square miles in area and far away from any other land. Starting in August 1954, sterilized flies were released by airplane at the rate of about 400 of each sex per square mile every week until January 1955. No fertile eggs were obtained on trap goats at eleven stations after October and the fly is apparently totally extinct on the island with consequent great improvement in the health of all livestock (4).

Since the purpose of this work was to eliminate the screwworm from the southeastern part of this country, operations were moved to Florida and a region of about 2,000 square miles around Orlando was selected for a larger scale operation. It was necessary to plan for rearing, irradiation, and dispersal on a greatly expanded scale and the field work could not be done until the 1957 season. On the basis of success in that region, an even bigger program has been set up for the whole breeding area in southern Florida, amounting to about 50,000 square miles. An idea of the magnitude of this undertaking may be gained from the following specifications. Rearing is done in an airplane hangar 160 x 200 feet with a second floor added, and irradiation is by use of six Co$^{60}$ units in a structure 32 x 76 feet. Fifty million sterile flies per week are provided for and 75,000 pounds of meat will be needed each week as feed for the larvae (27).
This is an expensive undertaking but it is a single cost and cheap in comparison with the recurring losses from the insect and it sets an example for similar campaigns in other regions, not only with this insect but with other pests. An example is given by several destructive fruit flies in Hawaii. Once exterminated in the islands, they could be kept out thereafter by quarantine and inspection. It has been suggested that the tsetse fly in parts of Africa may be subject to the same procedure and mosquitoes in many regions are also possibilities. Each case requires detailed laboratory examination and pilot scale trials before a conclusion can be drawn but it is obvious that a new and powerful measure for insect control is available. An example of work on this pattern is given by tests on sterilization of the white-pine weevil. Sterility of both sexes is obtained by exposure to Co\textsuperscript{60} gamma radiation at the rate of 5,000 to 20,000 r. The situation is more complicated than in the case of the screwworm fly for the female accepts more than one insemination. Sterilized males are able to negate previous insemination by a normal male and vice versa (24). Hence the ratio of sterilized to unsterilized males must be considerably greater than with the screwworm in order to obtain reasonably fast reduction in numbers.

The term insecticide includes all substances which are toxic to insects because of their chemical nature, in contrast to the direct effects of radiation discussed in the foregoing section. The magnitude of insecticide usage causes them to be a major expense of agriculture and a source of concern to many persons interested in public health. Thus in the United States alone nearly three hundred million pounds of insecticides are consumed annually, most of this huge amount going into agriculture. Estimates of the return in increased production and improved quality are necessarily largely qualitative but there can be no doubt that the food and fiber needs of the nation are completely dependent upon a supply of effective insecticides. To a large degree this is true for any other part of the world also.

It is axiomatic that the highest attainable efficiency in use of chemicals for insect control is desirable both for economy in agriculture and to keep contamination of food at a minimum. Chemists and entomologists of industry, government, and experiment stations are constantly seeking better insecticides and improved methods of use. The advent of DDT in the early 1940's and of other chlorinated hydrocarbons since then raised high hopes that many destructive pests would no longer claim their heavy toll. But the development of resistance, leading first to the need for heavier applications and then in many cases to failure at any practical dosage, has brought the solemn realization that the menace from insect pests is as serious as ever.
The rate of development of resistance and the level reached vary from one species to another and differ greatly among insecticides. With the hope of restoring the effectiveness of materials already outmoded and of finding others to which resistance cannot develop, a great volume of both practical and basic research has been brought to bear on the problem. This varies all the way from tests of new wetting agents for improving deposit of sprays to study of the changes undergone by insecticides after absorption into susceptible and resistant insects.

The study of how insecticides are metabolized in insects, and also in plants and animals, has been aided greatly by use of labelled insecticides containing C\textsuperscript{14}, P\textsuperscript{32}, or S\textsuperscript{35}. These can be detected and estimated quantitatively in amounts many fold lower than any chemical technique permits. This sensitivity is especially valuable with the small amounts of material available from insects. The combination of radio-tracing and paper chromatography has permitted progress at a speed impossible by older methods. A typical research on the metabolism of an insecticide in an insect is done in the following manner. At chosen intervals after exposure to the labelled insecticide, which may be by feeding in a bait, topical application in a solvent, walking the insect on a treated surface, etc., the whole body or chosen tissues are extracted and the solution separated into components on a paper strip chromatogram. The strip is passed beneath a detecting device, usually a Geiger tube, and the amount of radioactivity at each point is measured. If the impulses are fed into a recorder a permanent radioactivity chart is obtained in which each peak indicates a radioactive compound. By comparison with similar radiographs made with chosen amounts of the insecticide and known derivatives it is possible to determine quantitatively the course of metabolism of the insecticide, though positive identification of all metabolites usually is difficult.

The first use of this procedure was with C\textsuperscript{14}-DDT in houseflies. Chemical tests had shown that resistant flies dehydrochlorinate DDT to form the nontoxic DDE but there was uncertainty regarding the importance of other possible metabolites. By radio-tracing it was proved that formation of DDE is quantitatively the predominant reaction in resistant flies during the first ten or twelve hours during which their fate is decided (38). However, other more polar substances are formed after longer periods and are gradually excreted by surviving flies (23, 48). From this it is reasoned that a chemical which would interrupt the dehydrochlorination process should restore DDT's efficiency, and several synergists have been found to act in this manner (47).

In some insects resistance to DDT is due to the same mechanism as in houseflies but in others such as the roach an entirely different series
of metabolites are obtained from the start and DDE cannot be detected (23). Mosquito larvae form both DDE and the other metabolites. While a complete investigation has been made with very few species it is clear that resistance to DDT is not due to a single process common to all resistant species but varies among them. Hence a rational attempt to overcome it must take into account these differences.

Similar work with the toxic isomer of hexachlorocyclohexane (lindane) has shown that the first step in metabolism is less of HCl and that later several compounds of increasing water solubility are formed (5,6). An unexpected result was obtained with certain of the polycyclic chlorinated hydrocarbons. Aldrin and dieldrin differ in that the structure \(-\text{C}=\text{C}\)\text{H}\text{H}\) in one ring of aldrin becomes the epoxide group \(-\text{C}=\text{C}\text{H}\cdot\text{C}\text{H}\) in dieldrin. By radiotracing and chromatography it has been established that in several insects so far tested, aldrin is changed to dieldrin and the indication is that the toxic action is dependent upon this process (10). Similarly, heptachlor is inactive until it is converted to the epoxide after absorption. Resistance has developed to these compounds in several important agricultural pests, but the way in which this comes about has not been investigated carefully. Two possible mechanisms may be suggested: either the activating process is decreased, or a detoxifying reaction occurs, which probably is not a dehydrochlorination. By use of tagged chemicals this interesting and important problem can be investigated readily.

Soon after parathion was introduced as a contact insecticide the discovery was made that in its original form it has low toxicity and but feeble inhibitory power upon the enzyme cholinesterase, which is its most obvious action within all organisms. But toxicity and inhibiting power increase greatly when it is converted to the oxygen analog, paraoxon, in which the group \(=\text{P}(=\text{S})\text{-}\) is replaced by \(=\text{P}(=\text{O})\text{-}\). Since this reaction occurs rapidly within insects, parathion has a wide spectrum of activity against many insect species. It appears to be generally true that compounds having the \(=\text{P}(=\text{S})\) group are inactive.

The proprietary material Systox contains two isomeric components, the so-called thiono form which is \((\text{EtO})_2\text{P}(=\text{S})\text{-}0\text{-C}_2\text{H}_4\text{SC}_2\text{H}_5\) and the thiol form which is \((\text{EtO})_2\text{P}(=\text{O})\text{-}S\text{-C}_2\text{H}_4\text{SC}_2\text{H}_5\). The latter is much more insecticidal and cholinesterase-inhibiting, and it is formed from the thiono by heating, e.g., at 130°C for a few minutes. The behavior of these compounds as toxicants for insects and as cholinesterase inhibitors is complicated by the fact that oxidation of the sulfur in the sidechain increases both effects and at the same time makes hydrolysis to inactive diethyl phosphoric acid more rapid. Application of P\(^{32}\) thiono Systox to
the American roach via the oral, topical or spiracular route resulted in rapid accumulation in the gut of radioactive substances whose movement in a chromatogram indicated the original compound plus the thionosulfoxide (i.e., \(-S(=O)\)- in the sidechain) and diethyl phosphoric acid sulfoxide (31). This latter compound which has the \(=P(=O)\)- group is a very strong inhibitor of cholinesterase. After similar application of the \(p^{32}\) thiol isomer the gut contained only the unchanged material and its sulfoxide. Muscle and nerve tissue of the roach contained smaller amounts of the same compounds as those found in the gut. It is significant that the relatively nontoxic thiono compound is changed to a highly toxic derivative in the insect body.

The compound octamethyl pyrophosphoramid e (OMPA for convenience) has been given the common name schradan in honor of its discoverer, Gerhardt Schrader. Its structure may be written as \((CH_3)_2N_2P(=O)--P(=O)N(CH_3)_2\). It has found extensive use for control of plant sucking aphids and mites. Although the substance has two \(=P(=O)\)- groups, it is relatively low in cholinesterase-inhibiting power until activated by oxidation. This oxidation does not occur on P or S as in the other phosphorus insecticides discussed earlier but on an amide N, given the group \(-N(=O)(CH_3)_2\) or \(-N(OCH_3)CH_3\). Much confusion has come from the experimental facts that nonoxidized schradan is highly toxic to insects though a very poor cholinesterase inhibitor and that the oxidized material may be less toxic than the original when administered to insects. By use of \(P^{32}\)-labeled materials it was shown with the citrus red mite, cowpea aphid, and mosquito larvae that regardless of its route of entry, oxidized schradan is rapidly hydrolyzed within insects and that schradan itself is readily oxidized to its reactive form (39). It therefore is a matter of relative speeds of reaction, whereby enough of the intact material penetrates to the site of action where it is oxidized and exerts the toxic effect. A higher rate of hydrolysis in rat tissue than in the roach (2), if true for animals and insects in general, is a factor making for less hazard from use of the material.

In the application of the older insecticides to plants to kill insects feeding thereon, the plant acted only as an inert support for the toxic material and played no marked role in its effects. But when certain of the organic phosphate compounds were used upon plants it became apparent that several processes occurred: the insecticide penetrated into the plant and was carried about by the circulating fluids, it was activated in some cases to a more toxic and enzyme-inhibiting form and it was degraded to inactive products by hydrolytic processes. The name "systemic" has been used widely for such materials. The situation is
similar to what occurs when these compounds enter into insect tissues but is more complicated because of the extensive movement that occurs in plants. By use of P\textsuperscript{32}-labeled compounds most of the story has been clarified for several chemicals and it may be said without reservation that the organic phosphates naturally present in plants would have made this well-nigh impossible without the tracer technique.

Not all the phosphorus-containing insecticides are systemic, e.g., tetraethyl pyrophosphate (TEPP), parathion and paraoxon are not because they are hydrolyzed very rapidly to nontoxic degradation products (17). There is a general tendency for radioactivity to concentrate in the young or growing tissues of plants exposed to P\textsuperscript{32}-labeled insecticides, e.g., young pineapple plants after treatment of soil about their roots with P\textsuperscript{32}-labeled Disyston have fairly uniform distribution throughout but in older plants the P\textsuperscript{32} goes to new tissue (9). In bean, lemon, and cotton plants the thiol isomer of Systox penetrates several times as rapidly as the thiono form (33,14,15), and both tend to collect in the outer edge of the upper leaves. Both are metabolized rapidly, e.g., less than 20 percent of the original material is left after 24 hours. Other studies with P\textsuperscript{32}-labeled Systox have shown that it travels in the cotton plant primarily in the xylem system and consequently very little gets into the nectar (1,49). If this proves to be the case with plants in general, there will be no reason to fear contamination of bee bread or honey as a result of use of Systox at or before blossom time.

The isomers of Systox follow the same general metabolic path in insects (roach), plants (bean, lemon, etc.) and animals (mouse) as follows: each is oxidized successively to its sulfoxide \(-S(=O)\) in the sidechain and to the sulfone \(-(O=)S(=O)\) in the sidechain (31). The thione also forms the phosphate sulfoxide by replacement of the sulfur on the P with oxygen, i.e., \(\equiv P(=S)\) becomes \(\equiv P(=O)\), thus giving a highly toxic derivative. Further metabolism is to nontoxic diethyl phosphoric acids and alcohols. In this series of products the sulfones are the most cholinesterase inhibiting. The thiol series is in general more active as a toxicant and more readily hydrolyzed.

Schradan is rapidly transferred to the leaves of treated plants. Since activity of leaf extracts in cholinesterase inhibition is not proportional to total radioactivity, it follows that the inhibiting metabolites do not accumulate (32) but exist at a low level in a dynamic balance between formation by oxidative processes and hydrolysis to noninhibiting degradation products. The rapid activation in insects previously mentioned (39) makes the activation process in the plant of no importance. In fact, it may be detrimental because of the rapid further hydrolysis of the activated product which thus depletes the amount available. The
nectar of mustard and borage has been found to be contaminated with $^{32}$-schradan (up to 21 ppm) over a four weeks period after spraying. Since schradan is stable in honey it is possible to have serious contamination of this product unless spraying is stopped at least a month before bee activity (18). Schradan accumulates strongly in the oily seeds of cotton, e.g., an application of $^{32}$-labeled material at the rate of one pound per acre gave 8 to 16 ppm in raw oil. Fortunately, this is almost all removed during refining (34).

From the voluminous literature on radioisotopes in insects and treated plants only a few other items can be mentioned. When Chrysanthemum cinerariaefolium plants are grown in an atmosphere containing Cl$^{14}$O$_2$ they form Cl$^{14}$-pyrethrins and cinerins (36), which are the insecticidal ingredients of most fly sprays. These compounds and the related synthetic material allethrin are rapidly detoxified in insects. This is shown by the dramatic revival of apparently dead insects following application of insufficient amounts of these materials. By use of labeled compounds and paper chromatography the nontoxic degradation products can be isolated (51). Both absorption and metabolism of the materials were decreased in the presence of the synergist piperonyl cyclonene.

The formation of nicotine in the tobacco plant has long been a poorly understood process. By supplying Cl$^{14}$-methyl labeled methionine to a plant it was shown that the methyl group of methionine is a precursor of the methyl group of nicotine (7). Cl$^{14}$-formate also can furnish Cl$^{14}$ to the methyl group of nicotine. It is obvious, apart from the connection with insecticides, that great progress can be made in general plant physiology by use of such techniques.

Residual insecticides in foodstuffs have been the subject of very much scientific and legal activity for several years. Public Law 518, often called the Miller Bill, which was enacted in 1954, set up procedures for registration of pesticides by the U.S. Department of Agriculture and for the establishment of so-called tolerances by the Food and Drug Administration. No other law has ever laid such a burden upon chemists and entomologists, for it was necessary to find methods for quantitative determination of the micro amounts involved, to apply these methods to a wide variety of contaminated products, to correlate the results with the insect control programs from which they resulted, and lastly, to formulate recommendations that would give satisfactory protection of the crops and yet not lead to residues in excess of the tolerances. With insecticides which undergo no metabolic changes when applied to plants (or animals) this was a straight forward problem in microanalysis. But with those numerous materials such as aldrin, schradan, Systox and with a large number just now coming into use there was, and is, the
question of what should be analyzed for and what compound should be used as the basis for expressing results.

In this task, labeled insecticides are an indispensable tool. About three dozen have now been produced with a radioactive element and it has become almost obligatory for the concern that introduces a new pesticide to make it and its probable metabolic derivatives available in labeled form. Taking Systox as an example, it is customary to use the commercial mixture of thiono and thiol isomers (approximately 2 to 1) as the standard for determination of residues by cholinesterase inhibition. But since the chief products are the sulfoxides and sulfones which are several times as active as inhibitors, the residue so calculated will actually be too high by the same factor. The opposite case is that of the phosphate Thimet in which the sulfone is produced by oxidation in vitro and used as the standard. But actual residues are not all sulfone. Numerous other examples such as heptachlor versus its epoxide could be cited. Obviously, a great deal remains to be done in establishing standard compounds for residue determination and in this task labeled insecticides and their metabolites are indispensable.

Another aspect of food contamination lies in reactions which may occur between the pesticide and some constituent of the food. Thus by use of C\textsuperscript{14}-methyl bromide it has been found that when grain or flour is fumigated with methyl bromide a certain portion reacts by methylating the amidezole ring of the amino acid histidine (52). The product formed offers no health hazard and fortunately no vitamins seem to be inactivated. A similarly fortunate situation prevails in case of dried fruit fumigated with ethylene oxide (20). By use of C\textsuperscript{14}-(CH\textsubscript{2})\textsubscript{2}O on dried prunes it was shown that over half the radioactivity becomes associated with cellulose in the skin and nearly a quarter with sugars in the pulp. No materials of probable toxic nature are formed. These few examples must suffice as demonstrations of the supreme value of radioisotopes in the study of residual insecticides in foods.

The behavior of insects, especially their rate of movement and degree of dispersal under various conditions, their reaction to stimuli, the amount of fluid imbibed during sucking of plant juices, and the injection of saliva along with virus or other plant poisons, are all subjects in which radioisotopes have been used very advantageously. "Tagging" has been done in several ways, which may be illustrated by a number of examples. Grasshoppers of the species Melanoplus mexicanus were fed on mash to which 2 millicuries of P\textsuperscript{32} had been added as potassium phosphate in one pound bran plus fifty milliliters molasses. When released in an alfalfa field none moved more than 30 yards away within twenty days (3). White-pine weevils to which a solution of Sc\textsuperscript{46}Cl\textsubscript{3} was applied could be
detected by a Geiger counter at a distance of five feet. The disputed question of whether they take wing and fly freely was answered affirmatively up to one hundred yards (19).

A very interesting technique has been used in studying the movement of wireworms under ground (13). A tiny segment of wire containing Co$^{60}$ was cemented to the dorsal caudal segment and the worms were permitted to move as they pleased between clean soil and soil treated with various insecticides. Movement was followed by a detector tube and not only lateral position but depth could be determined without disturbing the insects. They showed a strong avoiding reaction from benzene hexachloride and other widely used soil insecticides. As long ago as 1946, a Ra$^{226}$ disc was attached to the underside of click beetles' wings in order to follow their movements in the soil (50).

In connection with the Co$^{60}$ irradiation campaign against the screwworm previously discussed, the rapidity and extent of natural movement of the adults was studied by rearing the larvae in a medium containing P$^{32}$ at 0.2 to 0.5 microcuries per gram. This gave sufficient activity in the resulting flies so they could be identified from traps up to four weeks later (42). The fruit fly, Dacus dorsalis, may be tagged by feeding on sugar solution containing P$^{32}$. In addition to the natural rapid decay of this radioactive element, female flies lose it more rapidly than males because it passes into the eggs (44). Some rarer radioelements, Zn$^{65}$, Sr$^{89}$, and Zr$^{95}$, have been used in migration studies with the plum curculio. The last isotope is especially useful because its penetrating $\gamma$ radiation can be detected from a considerable distance (43).

The feeding of several species of aphids results in serious plant injury in the vicinity of the feeding puncture. It has been a mooted question whether this is the result of removal of cellular nutrients and consequent tissue starvation or whether some toxic substance(s) in the insects' saliva is injected. To test this with the green peach aphid on tobacco plants, the aphids were made radioactive by feeding on plants grown in soil treated with P$^{32}$-phosphate. Then they were placed on non-radioactive tobacco plants and precautions taken to show that honey dew did not reach the points where the sucking tubes were inserted. After some days autoradiographs of the leaves showed intensely hot spots thus proving that radioactive saliva had been injected (28). The volume of saliva injected by an insect during feeding may be determined by the amount of radioactivity in leaves after a feeding period. For instance, the tarnished plant bug, which transmits several serious plant diseases, injects 0.05 to $0.25 \times 10^{-3}$ ml at each feeding on such host plants as the bean (12). Two-spotted mites allowed to feed on bean plants grown in P$^{32}$ culture solution become radioactive and transfer part of this
activity to new leaves during feeding at a later time. During egg forma-
tion in the female much of the contained $P^{32}$ goes into the developing
embryo, the ratio of $P^{32}$ to volume being three times as high there as in
the mature female (45).

An account of the use of radioisotopes in agricultural entomology
would be incomplete unless it took some notice of their expanding role
in studies on the ordinary biochemistry of insect life. While much of
this work has only a remote connection with agriculture, it is supplying
the basic data through which such practical matters as action of insecti-
cides, development of resistance, nature of insect disease, etc., can
eventually be understood. The intimate details of insect biochemistry
and physiology are being reported upon in hundreds of articles, many of
which are concerned with the use of radioisotopes. It is impossible to
give more than a very few examples of some lines of development.

The behavior of insect integument as a semipermeable membrane is re-
sponsible for the ability of insects to exist in a wide variety of en-
vvironments. The larva of the crane fly, Tipula paludosa, which lives in
the soil, has been shown to absorb $K^{42}$ more rapidly than $P^{32}$ in phosphate
and the cuticular permeability is asymmetric for these two elements (46).
The cricket, Gryllus bimaculatus, has a black and a yellow pigment in its
outer layer, the cuticula. Injection of $C^{14}$-tyrosine caused the black
pigment to become radioactive (16). On the other hand, injection of $C^{14}$-
tryptophane led to radioactivity in two other pigments located in a deeper
layer, the hypoderm. When $I^{131}$ is fed or injected into the American
roach it becomes strongly concentrated in the integument as
3-monoiodotyrosine. Insect muscle forms diiodotyrosine and thus acts
like the thyroid gland in mammals. The fat body is the site of formation
of thyroxin whose function in insects is still unknown (29).

An ingenious method for distinguishing between essential and nones-
sential amino acids for insect nutrition is based on supplying $C^{14}$-labeled
glucose to an immature stage and determining which amino acids in the body
become labeled. Thus with the blue bottle fly uniformly labeled glucose
was injected into third stage larvae. Three days later the larvae and
pupae formed by that time were ground and extracted and the amino acids
were obtained and chromatographed by standard means. Those amino acids
which were highly radioactive were glycine, serine, glutamic acid and
aspartic acid all of which are known not to be essential. All other
amino acids contained little or no $C^{14}$, from which it was reasoned that
they are not formed within the insect and therefore must be supplied in
food (25). Certain discrepancies from the classical depletion method of
determining essentiality of food constituents were found which need fur-
ther study.
The sulfur metabolism of insects may be studied advantageously with $^{35}\text{S}$. Thus the roach has been found able to form methionine and cystine from inorganic sulfate but the housefly cannot (21,22). From ingested or injected $^{35}\text{S}$-cystine the housefly can form glutathione and taurine and large amounts of inorganic sulfate are excreted. The whole sulfur metabolic complex has been determined by paper chromatography of extracts from flies supplied with $^{35}\text{S}$ in various compounds (11).

The work with $^{35}\text{S}$ is an example of the so-called "labeled pool" technique (53). This involves supplying the desired element in a readily assimilable form e.g., as phosphate for $^{32}\text{P}$, and after a time extracting from the tissues all labeled constituents under conditions that prevent or minimize further changes. This is done first for the normal insect (40). Repetition with the same species under altered conditions such as starvation, fatigue, poisoning, etc., will show which labeled constituents are altered in amount and throw much light on the biochemical processes involved. As an example, methyl bromide affects the phosphorus metabolism of the adult housefly by depleting it of adenosine triphosphate, arginine phosphoric acid and phosphoglyceric acid. It thus has much the same effect as iodoacetate in mammals (54). By administration of $^{14}\text{C}$-acetate the carbon pool may be labeled in a similar manner. It will be obvious that an immense field or work is opened by this use of isotopes.

The foregoing discussion has touched on many subjects which obviously are capable of tremendous development by the use of radiations and tracer elements. Prophecy concerning future progress in science is notoriously inaccurate but with an eye only to the near future there seem to be three applications of radioactivity to agricultural entomology that surely will be of outstanding significance and are worth the time and thought of many skilled researchers. These are: further application of radiations to reduce or exterminate more pest species at least from certain areas; further study of the changes undergone by insecticides within insects, plant and animals, in order to develop better procedures for determination of pesticide residues, to understand some of the biochemical changes that take place when a population becomes resistant to a chemical and to gain a better understanding of the action of insecticides upon living matter; and lastly, further search in the unexplored ocean of normal insect biochemistry which will throw much light on all manner of biological problems.
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* Publications marked with an asterisk (*) are based upon research done on grants from the Atomic Energy Commission.
A TECHNICAL REPORT ON ISOTOPES IN AGRICULTURE--GENETICS

C. F. Konzak, Associate Professor of Agronomy and Associate Agronomist
State College of Washington, Pullman, Washington

Introduction

The generalized application of radioisotopes and radiation techniques in genetics research will have a significant effect on world agriculture. But because most applications involve basic problems or problems that require years of work only a small measure of the potential material benefits have yet evolved.

The birth of genetics as a science in 1900 was preceded only four years by Bacquerel's discovery of natural radioisotopes. The injurious effects of radiation on plants and animals were soon recognized. A 278 page review of the effects of radium rays on plants was published as early as 1908 by Gager. Many researchers correctly suspected that radiation could induce mutations which were recognized as the foundation for genetic variation and evolution, but it was not until 1927 and 1928 that conclusive, unequivocal proof of the artificial induction of mutations by radium and X-rays was presented, respectively, for animals and plants by Muller and Stadler. The potential importance of radiation was soon recognized over the world, and in only a few ensuing years artificial mutation research had begun in Sweden, Russia, Germany, and India. Still, radiation genetics research was limited to a few laboratories where X-ray facilities, or the rare and expensive radium sources were available. (Perhaps, this period of seemingly slow development was a fortunate situation--otherwise, more scientists would have later succumbed to cancer as the result of their careless [by today's standards] use of radiation.)

Artificial radioisotopes discovered first by Curie and Joliot in 1934, were the next historically most important advance. The use of radioisotopes in studies of nutrition, however, was recognized as early as 1923 by Hevesy. The use of tracers for cytotgenetic and mutation studies was an outgrowth of nutrition experiments. Knowledge that phosphorus played an essential role in the cell as part of the nucleic acid led to investigation of P³² as a mutagenic agent. Today tracer techniques are essential to cytochemical and biochemical research in genetics. The potential use of tracers is considerable, as will be discussed later.
With the advent of the atomic pile, the use of isotopes in agriculture became widespread. In the United States particularly the Atomic Energy Act of 1946 and the amended Act of 1954 authorized and directed a civilian commission to arrange for the conduct of research and development activities related to (1) utilization of special nuclear and radioactive material for biological, medical, agricultural, and health purposes, and (2) protection of health and promotion of safety in research and production (Craus).

Fortunately, basic radiobiological research conducted over the previous period by relatively few investigators provided a foundation for the expansion. General awareness of the Atomic Age in biological research soon became a reality. National research laboratories were created to conduct basic and practical studies involving radiation and radioisotopes. Stimulus was also given to research programs at colleges and universities through contract research, private foundations; both private and public universities supplemented Federal Atomic Energy Commission and Public Health Service support of research on the interactions between radiation and living matter. Today, the application of radiation in research, and facilities for the use of tracer techniques are commonplace at nearly every university and research institute.

While radiation genetics got off to a good start in the United States in the early 30's, extensive exploration of some of the more practical potentialities of radiations as mutagenic agents was limited. Geneticists became so impressed by the obvious destructiveness of radiations after viewing the cytological and genetic changes they so readily induced that they discouraged attempts to seek useful mutations on the grounds that it was virtually fruitless. They reasoned that if radiation could break and delete segments of chromosomes which contain the discrete gene units, only destructive effects could result. Stadler's views were supported by facts. Virtually all mutations he induced in barley and maize were recessive in inheritance and destructive in their apparent effect on the plant. Considering his work in the light of present day results, it appears that he failed to grow large second generation populations of treated material to maturity, and limited most of his studies to defective seedling characters or, in maize, to endosperm gene changes. He held tenaciously to the view that radiation could cause only destructive changes, even though Muller had repeatedly pointed out that in Drosophila radiation had induced all types of mutations that had yet appeared in nature. Recently, Caspar and Singleton apparently resolved the discrepancy between the maize and Drosophila mutation results. They noted that the relative amount of "gene" mutations identifiable by the fact that the mutated genes are transmissible through pollen was
influenced greatly by the time of irradiation. Their results indicated no basic difference between spontaneous and radiation induced mutational events.

Fortunately, for genetics and agriculture, Swedish workers (Gustafsson et al) took the optimistic approach viewing the destructive effects of radiation primarily as a means to an end. Mutations, they reasoned, were mostly destructive--even if from spontaneous origin. Gustafsson speculated that a small proportion of the induced changes might be useful in breeding improved crop varieties. On finding some unusually stiff erect strawed variants his optimism was stimulated and progress on a more positive approach to the use of ionizing radiation was underway. This development is well described in two Swedish publications (in English) "Svaløf" 1846-1946 and "Swedish Mutation Research on Plants," a group of papers published together in Acta Scandinavica in 1954. Today, the Swedish mutation research group is one of the most active and advanced research teams in the world.

The stimulus of Gustafsson's progress regenerated work in the United States and elsewhere following his publications of 1941 and 1947, and today with the stimulus of the Atomic Energy program and the interest in peaceful uses for isotopes, research in America is as strong and progressive as that anywhere in the world (see also Claus).

Radioisotopes in Modern Genetics

Use as tracers--Radioisotopes have enabled scientists to pry more deeply into the basic workings of the cell than would otherwise have been possible by even the best microchemical techniques. Chromatography, autoradiography, and activation analysis techniques have been improved and adapted to the broad range of specific applications (see Benson et al).

The radioactive isotopes $^{32}\text{P}$, $^{14}\text{C}$, $^{35}\text{S}$, $^3\text{H}$, and to a lesser extent $^{90}\text{Sr}$, $^{45}\text{Ca}$, $^{59}\text{Fe}$, $^{89}\text{Sr}$, have figured most importantly in studies on gene function, chromosome reduplication, and of the localization of certain elements in the cell. Radioactive phosphorus was studied as early as 1936 in nutrition studies (Spinks) and was known to be accumulated in the cell nucleus and to cause chromosomal aberrations by 1948 (Arnason). The importance of phosphorus in the nucleus is now fairly well established.

Taylor employed radiophosphorus in experiments to determine by means of $^{32}\text{P}$ incorporation the time of chromosome doubling at meiosis in Lilium. The development of autoradiography at the cellular level has been a most spectacular advance in genetics. Some of the earlier techniques were
outlined by Taylor in 1956. More recently, the search for greater precision in autoradiography has led Taylor et al to use tritium for studies of chromosome organization and reduplication. Tritium-labeled thymidine was readily incorporated in the chromosome and, being an essential component only of DNA, was incorporated in no other cell structure. By timing the application of the radioactive thymidine with known cell division and ingeniously utilizing colchicine to cause the dividing chromosomes to remain attached at their centromeres, it was shown that the "new" chromosome was synthesized intact using the "old" chromosome as a template. Chromosome duplication was later shown to occur on the chromatid level. Analysis of chromatid exchanges in Bellevalia led Taylor to further conclude that the two strands (chromatids) of a chromosome are unlike, their parts not free to reunite at random. The results of these studies showed that the chromosome has at least two features in common with the hypothesized Watson-Crick model of DNA—that (1) the chromosome has two strands, and (2) the strands are in some way different, in some structural feature. This work is extremely important and forms a basis for understanding genetic mechanisms, and a foundation for the whole field of Genetics, Cytology, and Mutation Research. This knowledge will be quickly applied to further other lines of research. Resolution by the use of tritium has been possible to the chromatid or half-chromosome level. This is due to the fact that the Beta rays emitted in tritium decay are of relatively low energy, hence have a shorter path in autoradiographic film than the Beta rays of P³², leading to less overlap of tracks in the film and to greater resolution. Other incorporation studies using tritium to study turnover have shown that there is some exchange of thymidine in nuclei of cells of different parts of the plant (LaCour and Pelc). More recently, Woods and Taylor have used tritiated cytidine and uridine to reveal the function of nucleolus of the cell in the synthesis of RNA. The role of the nucleolus has long been a puzzle to cytologists, geneticists, and cytochemists. Their conclusive evidence showed that the nucleolus is either the only site of RNA synthesis in the cell or is concerned with accumulating RNA that was synthesized elsewhere.

The studies showed also that RNA is transferred to the cytoplasm as a large molecule, and that RNA and DNA syntheses are independent processes. Again, the fundamental importance of these studies made possible only with thymidine is so great that their value cannot easily be estimated.

Steffenson (personal communication) is utilizing Ca⁴⁵ and Fe⁵⁹ to study the incorporation of calcium and iron in the chromosome of the cell. Unfortunately, the resolution tracks made by these radiosotopes are not like those of tritium, but by utilizing a pollen tube technique
in which the chromosomes of Tradescantia line up single-file, he should obtain conclusive data on the importance of these elements in the genetic apparatus.

Carbon 14 has been widely used in physiological studies in plants and animals. Its half life and more energetic Beta ray limits its usefulness in cytogenetic studies. However, it has been and will continue to be important, and will find increasing use in research to elucidate the function of genes. The identification of genetic blocks produced by induced mutation in metabolic pathways can reveal much about the relation of genes to metabolic functions in the living organism. Fuller (personal communication, Brookhaven Lab.), for example, has demonstrated that the genetic block causing albinism (lack of chlorophyll) in one induced barley mutant involves a primary carbosylation reaction. A more thorough study of interrelationships between mutants and their biochemical blocks may help to accelerate progress on the problems concerned with photosynthesis. These studies can most satisfactorily be conducted with labeled compounds.

Radioisotopes Applied Internally as Mutagenic Agents

Arnason et al demonstrated that radiophosphorus incorporated into wheat and barley plants could induce chromosomal aberrations and mutations. Osborne and Elliott studied $^{32}P$, $^{35}S$, and treated seeds compared with seeds exposed to X-rays and thermal neutrons. Sublethal treatments with the radioisotopes did not alter the interchange frequency, whereas, the X-ray treatment was effective. Swedish workers (Thompson et al) (also see Ehrenberg) have obtained mutations and chromosome aberrations in barley, however, after soaking seeds in $^{32}P$ and $^{35}S$ and from treatments with radon gas. Their results suggested that a slightly different spectrum of mutations compared with X-rays may have been induced by the internally bombarding radioisotopes. The work seems not to have continued, however, even though their results seemed encouraging. More than likely, the problems concerned with dosimetry, biological factors influencing uptake and sensitivity, and the hazards of handling have been such that other means of treatment have seemed more promising. That has been the view of the present author and his associates. Someday, after we have solved many of the problems we are presently concerned with, it may be profitable to reinvestigate and re-evaluate internal emitters. Several investigators working with Neurospora have attempted to estimate the relative importance of radiation and transmutation reaction on damage and gene mutation, but their results have not been conclusive (see Straus et al).
Mutations Induced by Externally Applied Ionizing Radiations

This section will be devoted almost entirely to the work of plants since in most instances (at the present time) the cost of practical improvements by mutation methods in animals is likely to be prohibitive. However, radiation experiments now underway with poultry (Dempster) may point the way to a future use in that field. Certainly, this type of application is out of the question with larger more expensive animals because under our present relatively inefficient and haphazard methods there is far too much wastage. With plants, this wastage is not so expensive, and mass screening methods for identifying and isolating mutants can be developed. These points have been stressed by many workers in the field including Muller, MacKey, Horner, Osborne, and Konzak.

An important factor determining whether "mutation breeding" can be practical adjunct to regular techniques is the efficiency of the treatment. A number of studies have been conducted comparing the relative efficiency of different radiation sources and different agents for producing a given effect, and this research is still being done.(see Konzak, Gray, Powers, and Wood). Some other authors have concluded that radiations with higher ionization density are far more efficient as mutagenic agents than those with low ionization density. This is quite understandable, since the high LET radiation like neutrons is much less influenced by modifying factors. However, it can be shown as has been done by us, Caldecott, and by Ehrenberg's group in Sweden that by proper pre- and post-irradiation treatment the efficiency of low ion density radiation can be increased rather markedly to a point where it would seem that the efficiency of the two sources does not differ greatly. Moreover, it is our feeling (Konzak and Nilan) that by appropriate pre- and post-treatment of very low ion density radiations as, for example, gamma rays, we can markedly improve the relationship of induced mutation to induced injury and structural damage. Our most recent experiments employing temperature shocks as a post-treatment have been most promising in this regard. In these experiments seeds frozen during irradiation at -78°C were given a post-irradiation temperature shock in water at +60°C for 60 seconds. Compared with nonshocked seeds the shocked ones had greater survival to maturity in the field, showed less anaphase bridges and fragments at their first mitosis on germination; but showed almost as many, or in some cases, more mutations than nonshocked seeds. Seeds with different moisture contents reacted somewhat differently to the after-irradiation treatment. Hydration of X- or gamma irradiated

1/ Unpublished preliminary data of Konzak, Nilan, Legault, and Burger.
seeds in oxygen after irradiation can increase the effect of the radiation dose 5- to 8-fold. Compared with our moist seeds irradiated frozen, however, the relationship of aberrations and injury to mutations induced is not as good in the oxygen treatments. Oxygen after-treatment of dry seeds caused about a 7- to 8-fold increase in the effect of dose for injury and chromosomal aberrations, but only a 5-fold increase in mutations. The dose response of dry seeds hydrated at 30°C in the absence of oxygen is not readily explained, since chromosome aberrations increased steadily with dose. Survival of the dry seeds did, however, decrease more rapidly after the 60 Kr dose than was the case for moist seeds.

These results demonstrate progress in the improvement of efficiency of radiation as a mutagenic agent. Because we now know more about radiation than any other mutagen we can put it to practical use in the least time. Moreover, since our studies have indicated that the part of the electron track with the lowest ion density is most readily modified by pre- and post-treatments, we are now interested in sources that give us the greatest portion of that component. The gamma sources, especially Co⁶⁰, are thus preferred.

Another means for increasing the efficiency of mutation experiments is to make use of mass screening techniques common in the field of plant pathology, as a method for isolating mutants from large populations of treated material. This method was among the first used to isolate a useful disease resistant mutation. Freisleben and Lein in Germany isolated a mildew resistant mutation in barley in 1942. Since that time the method has been applied by several others (see Konzak) to find mildew resistant barley mutants, some of which are already being used for identifying physiologic races of the fungus. Other mutants very likely will take part in the improvement of barley by regular breeding techniques. Some of these have been described by the Swedish workers. They have produced barleys with stiffer straw, higher yield and other mutants so early maturing that they offer to push back frontiers of the barley growing areas in the North (see Ehrenberg, Von Wettstein, and Gustafsson and Tedin). In this country, Woodward (personal communication) has isolated a variant from irradiated Bonneville barley that the Utah Station expects to release to farmers in the fall of 1959. This mutant has lighter, brittle awns compared with the undesirable tough heavy awns of the parent. In addition, yield tests have shown it to produce a slightly higher yield of grain and to be slightly earlier maturing. This development required less than five years from the time of irradiation. He observed no mutation from irradiated Lemhi wheat that seemed useful in his locality.
A number of economically important mutations have been induced in several crop plants by various workers. Sparrow and Konzak compiled a list of some of these improvements (Table 1).

Bishop has obtained a mutation for red skin color in Cortland apple variety, a character that was not observed from natural populations. This sort of change has considerable economic value. Hough and Weaver have reported the successful development of a late maturing variant in the Elberta Peach which promises to become a new commercial variety. Other peach mutations have affected the firmness and texture of fruit flesh and the freestone condition of the pit. Improved yield has been gained in peas, oil mustard, and barley by Swedish workers and mutant strains of these crops are already in production. In the United States, a peanut variety with improved yielding ability induced by gamma radiation from Gregory's experiments has been released by the North Carolina Experiment Station. The new Michigan bean variety, Sanilac, was developed by hybridization using an apparently useless bush-type dwarf mutant induced in early mutation experiments. The "useless" mutant contributed factors that may make the variety better adapted for machine harvesting. Its upright growth makes it less subject to damage by disease. Thus, it can be said that the usefulness of a mutant need not be immediately apparent, and it should not be expected that all desirable mutations must be directly useful as improved varieties. Certainly this cannot be the case for an extremely early rice mutant recovered by Jodon. This mutant may have great value since it matures almost a month before the standard variety, yet in its present form it is virtually useless. Its desirable traits may some day be incorporated in an improved variety. Similarly, Beachell has isolated a type of short-strawed mutant in rice that apparently was previously unknown to rice breeders. This mutant alone may change the economic picture of rice production. Its value must be considerable.

Bekendam (personal communication) working in Suriname isolated radiation induced mutants in rice that had shorter and stiffer straw, some that were earlier maturing, others later maturing. He obtained mutants resistant to cercospora disease, and some that promised higher yield. Even the kernel size and shape was affected by mutation. Some mutants had longer panicles, others had a more vigorous tillering habit than the basic variety.

In wheat, short straw is a highly desired characteristic and until recently no satisfactory gene source was available. Japanese short-strawed wheats have now been incorporated in our breeding programs so the need for new short-strawed genes is less. However, short-strawed plants are rather easily identified and can be produced at a high frequency in
Table 1

**MUTATIONS INDUCED**

Some Examples of Useful or Potentially Useful Mutations or Sports Obtained in Plants by Irradiation

<table>
<thead>
<tr>
<th>Character Improved or Modified</th>
<th>Character or Direction of Change</th>
<th>Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Crop Plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease resistance</td>
<td>To stem rust, stripe rust, Victoria blight, leaf spot</td>
<td>Barley, oats, wheat</td>
</tr>
<tr>
<td>Insect resistance</td>
<td>To gall fly</td>
<td>Sesame</td>
</tr>
<tr>
<td>Growth habit</td>
<td>Shorter, taller, dwarf, giant</td>
<td>Barley, flax, oats, rice, wheat, flax, jute, sorghum, bean, pea, peanut, red clover</td>
</tr>
<tr>
<td>Maturity</td>
<td>Earliness, lateness</td>
<td>Barley, oats, soybean, barley, oats, wheat</td>
</tr>
<tr>
<td>Self-incompatibility</td>
<td>To self-fertility</td>
<td>Red and white clovers, tobacco, wheat</td>
</tr>
<tr>
<td>Quality</td>
<td>Improved</td>
<td>Oats, wheat</td>
</tr>
<tr>
<td>Yield</td>
<td>Increased</td>
<td>Oats, wheat</td>
</tr>
<tr>
<td>Hardiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Horticultural Plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease resistance</td>
<td>To rust</td>
<td>Black currant</td>
</tr>
<tr>
<td>Flower color, shape, size</td>
<td>Various</td>
<td>African violet, carnation, cyclamen, petunia, phlox, snapdragon, tulip</td>
</tr>
<tr>
<td>Self-incompatibility</td>
<td>Self-fertility</td>
<td>Sweet cherry</td>
</tr>
<tr>
<td>Growth habit</td>
<td>Varied</td>
<td>Black currant</td>
</tr>
<tr>
<td>Leaf shape and color</td>
<td>Various</td>
<td>African violet, apple, phlox</td>
</tr>
<tr>
<td>Quality</td>
<td>Varied improvement</td>
<td>Black currant</td>
</tr>
<tr>
<td>Fruit size</td>
<td>Increased</td>
<td>Black currant</td>
</tr>
<tr>
<td>Fruit color</td>
<td>Improved</td>
<td>Apple, pear</td>
</tr>
<tr>
<td>Time of ripening</td>
<td>Earlier and later</td>
<td>Peach</td>
</tr>
</tbody>
</table>

1/ Some of these mutants have been induced at Brookhaven, but the majority are summarized from published articles. Space does not allow references to the original literature citations, but most of these may be found in the articles by MacKey (1956), Smith (1958), Konzak (1957), and Sparrow, Binnington and Pond (1958).

wheat. Hence, it appears practical to use radiation to improve the straw characteristics of already desirable varieties. The experience of this writer is such that he believes it will be economically feasible to induce short-strawed mutants as a matter of course in the breeding program and experiments are now in progress to test the practice of the method. Through farmer cooperation, more than five acres of the second generation from two irradiated varieties are now being grown. At this station, short-strawed wheats are being developed as a regular part of the breeding program. Thus, there is an excellent opportunity to compare progress by the two methods. We are also seeking mutations from winter to spring habit in wheat in an effort to develop better ways to improve the cold hardiness of our spring wheats—giving them greater versatility, adaptability, and usefulness to the farmer. Almost three acres of irradiated winter wheat were sown in bulk plots this season to test the feasibility of this approach. Again, the cost of this type of experiment is quite small compared with the potential return. When sown in the spring, the normal winter habit variety will not head out at all or will head out late, and only the mutant types should mature plump seed.

Here, at Washington State College, we are following the progress of our basic studies by practical experiments supported on state funds to supplement our practical breeding programs. Improved characteristics we can readily use in the reconstruction of our crop plants will be of considerable value. Desirable mutants can be induced in quantitative traits.

Mertens and Burdick, for example, have shown that mutants with increased earliness and fruit size can be obtained in the tomato.

The list of improvements by induced mutation is much longer. Earliness in lupines has been induced by radiation and alkaloid-free variants of lupines have been found in irradiated populations (see Horner, Gustafsson, and Tedin). Coolhaas (see Konzak) discussed the usefulness of a yellow-green chlorophyll deficient mutant of tobacco, which produced under cultivation a better quality leaf than the normal variety.

The production of disease resistant mutants (mentioned before) may be one of the most important applications of mutation research in plants. Yet, the development of methods for induction and isolation of these mutants has not received adequate support. Progress in this area received a temporary setback earlier because in conducting the necessary large scale experiments adequate control of natural crossing was not obtained, leading to an over-estimation of the frequency of induced disease resistance. More recent experiments seeking stem rust resistance in oats produced a mutant type that was previously unknown and a known type, though the treated population was kept carefully isolated throughout its history.
A renewed effort using improved methods is vitally needed to develop this important application. Natural sources of disease resistance must be discarded yearly to meet the onslaught of new forms of pathogens, thereby reducing the stockpile of genes useful to the breeder. Disease resistance is seen as the potentially greatest need by the plant breeder. It has been said (Smith) that the modern plant breeder using radiation can, at will, study more variation in his crop in one season than he could otherwise expect to see in a similar crop during his entire lifetime.

The point is often claimed that we already have more variability than we can effectively use in many crops, and the uncertainty factor in the mutation breeding technique does not assure the breeder he will recover the desired types. This is now a fairly valid criticism, but only because not enough work has been done for us to know the characters that can be produced with greatest ease and how they may be recovered at least cost. Genetic principles on which plant breeding is based did not develop overnight. We believe that there are many needs that the technique could perform in a breeding program—even if the breeder has sources of desired genes in breeding stocks. It seems possible, for example, to induce a trait that is more simply inherited than those now used. Further, the induction of desired single traits in improved varieties can be faster and less costly than making the improvement by other means. We do not consider mutation breeding a substitute for other methods. We hold that the technique can be a useful tool and may eventually be our prime source of variations.

Mutation breeding is not readily applied equally to all agricultural plants because without complete control over the mutation of genes we must depend on random events, selecting only what is desired. Any inherent mechanism that tends to reduce the potential recovery of induced traits, makes a plant species less suitable. The cross-breeding nature of a plant if selfing is prohibited, reduced the frequency and efficiency at which an induced recessive gene may be recovered. If the size of the plant is such that a large cultivated area is needed, the cost of production may be too high.

On the other hand, certain mechanisms in plants make them especially suitable for mutation studies. In the cereals, self-pollinated types can be grown in large populations on a relatively small area, and a high percentage of mutants may be recovered in the second generation. In certain grasses, the mechanism of apomixis makes them suitable because a desirable induced somatic variant can be propagated by seed without involving the screening mechanism of the sexual phase.
Besides the practical applications, mutations induced in plants have important uses in fundamental studies. These concern their use in the genetic mapping of chromosomes--an aid to the breeder of improved crops, in studies on the mechanism of gene action, in studies on the nature of host-parasite relationships, in studies on physiological processes and, in studies on the nature, organization, and relationships of genes.

Radiations also induce chromosomal translocations and these have been most useful in the mapping of chromosomes in fundamental genetic studies. Anderson has pointed out that translocation may be very useful in breeding to aid in carrying blocks of genes that are not easily identified into a background in which their effect may be readily measured.

Perhaps more important, however, is the application of the translocation inducing ability of radiation for transferring genes from wild plant forms into cultivated species. Sears has already demonstrated the feasibility of this procedure by transferring a gene for general resistance to leaf rust from *Aegilops umbellulata* to common wheat. The variety of wheat which resulted from his seven years work is now in use in many areas of the world. For this feat Sears received the Kimber Award in Agriculture. Certainly we will receive much benefit from this accomplishment--especially when we consider that a 10 percent yield loss from the leaf rust has not been an uncommon event. Studies of Elliott at Washington have indicated that stem rust resistance from *Agropyron* (tall wheat grass) may have been transferred to common wheat. The same *Agropyron* species also carries an extremely valuable general type of resistance to the bunt or stinking smut disease of wheat and rapid progress is being made at Washington State College on this program. Since chromosomes of these wild species will not pair with cultivated crop plants, radiation offers the only means to transfer.

Still another application of radiation which may find use in plant breeding is the induction of haploidy in bread wheat by Natarajan and Swaminathan. These investigators demonstrated that haploids could be induced through a stimulus to parthenogenetic development following application of pollen from inflorescences exposed to 5,200 r of X-rays 3 to 4 days before anthesis. If the procedure is efficient one could visualize its use for the rapid development of homozygous offspring from hybrids.

The evidence already available reveals only a small measure of the potential return yet to be gained from the applications of radiation in genetic research. Economic benefits will be even greater in the future. That gained from only a few of the recent accomplishments may be enough to pay the cost of the whole support program in genetics.
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126


The plant breeder is being greatly assisted in his task of producing new and improved forms of plants by the new and potent sources of radiation which have become available with the advent of nuclear energy.

It has long been known that radiation, such as X-rays, induce changes (mutations) in genes and chromosomes which are stable and which are manifested in new traits in succeeding generations. Ionizing radiation produced from nuclear energy will act similarly and can increase the naturally occurring mutation rate by several thousand. This means that the artificial creation of mutation becomes a thoroughly practical tool for the plant breeder in the production of new forms. Most of the mutants so produced are "harmful" in the sense that they are of no improvement to man's interests, but perhaps one or two percent may be beneficial and can be used in the regular breeding routine. In addition, still other mutations which in themselves are not beneficial may be useful by providing a new beneficial character or characters which may be introduced into new forms by standard hybridizing techniques.

Little by little, the principles of positive or "beneficial" mutation techniques are being worked out so that certain desired forms can be produced by employing radiations of different ion densities such as Co^{60} gamma rays, P^{32} beta rays, X-rays and neutrons of different origin, and alpha rays.

In this way, cereals have been produced which are higher in yield than the parent forms, stiffer in straw, earlier ripening, possessing higher protein content, and adapted variously to highly fertile soil and soil of low fertility.

In this age of mechanization, such qualities as stiff straw and dwarfness may be highly desirable in adapting a plant to mechanical harvesting. The Sanilac bean is a case in point, which was produced by irradiation with X-rays and which possesses dwarf plant characters adapted to easier mechanical harvesting. This bean is now the dominant variety of white pea bean of the United States used in canning, amounting to over 2 million bushels a year, valued at over 15 million dollars.
New and improved barleys and mustards have been produced in Europe, and improved types of peanuts have been developed in North Carolina which are superior in yield, better adapted to mechanical harvesting, and resistant to serious leaf-spot diseases.

One of the most likely uses of irradiation is in the production of disease-resistant plants. Losses to farmers from diseases have been estimated at 3 billion dollars a year. Extensive tests with oat irradiations have shown that it is possible to produce resistance to stem rust, crown rust, and Victoria blight. Ionizing radiation thus suggests a means not only of reducing losses from present known plant diseases but also of meeting the hazard of new mutant disease organisms which are constantly appearing.

Mutations may be produced in somatic or body cells of a plant, in contrast to the germ cells. Many horticultural plants are of this origin, especially color variations such as red strains of apples, variegated carnations, and gigas forms of snapdragon.

Radiation studies have been conducted with over 60 different crop plants, with varying results. From this modest beginning it is not too much to expect that much eventual good will come. For example, 70 percent of the crop seed varieties grown today were unknown 20 years ago, and 90 percent of strawberry production in America is from varieties produced by scientific plant breeding.

Photosynthesis

Photosynthesis which is carried on in the chloroplasts of plant leaves is the basis of life on this earth. In this process, the energy of the sun is used to synthesize sugars, carbohydrates, and other organic substances from water and the carbon dioxide of the air. These compounds are consumed by animals and are the sole source of energy to sustain animal life.

An understanding of this process is one of the great and important goals of scientists in the hope that through this understanding it may be possible to increase plant efficiency if not actually control artificial photosynthesis.

With the use of radioactive isotopes it is now possible to describe in detail the pathway of carbon in the photosynthetic cycle, and in addition to outline the intermediate steps and the compounds involved.
In the process of photosynthesis, not only are carbohydrates synthesized but oxygen is released into the atmosphere. It has long been debated whether this oxygen was derived from the water molecule or the carbon dioxide molecule. Now, by the use of radioactive isotopes it has been conclusively demonstrated that the oxygen comes from the water molecule.

While most of the carbon dioxide is from the air, studies with radioactive isotopes have shown that carbon dioxide from the soil may be carried upward in the plant to the leaves and be utilized in the photosynthetic process.

It has been determined that the chlorophyll of plants is being constantly destroyed and renewed, and at a relatively rapid rate. Studies with oat plants, using N\textsuperscript{15} have shown that the chlorophyll may be renewed every 30 to 80 hours in 25-day-old plants. (A modern illustration of the essentialness of green plants to animal life is shown by the plan to include photosynthesizing green algae and lights in space ships so as to remove accumulating carbon dioxide from the atmosphere of the ship and replenish oxygen.)

**Alkaloid Synthesis**

The site and nature of synthesis of alkaloids and other organic compounds in plants has been illuminated by radioisotopes. A portable photosynthetic chamber of 60 cubic meter capacity has been placed over a 30-year-old pine tree and radioactive carbon dioxide introduced into the chamber. By this means, the optimal time for tapping for tarsins and tannins has been improved. Similar studies with rubber, tobacco, and cinchona are providing information which is of immediate practical value.

**Synthesis by Roots**

The root has been found to be an organ not only for the uptake of water and nutrients but also for the synthesis of a number of compounds present in the plant. Using C\textsuperscript{14}O\textsubscript{2} it has been shown that approximately 50 percent of the materials derived from photosynthesis in the leaves move downward as sucrose to the roots. There, the material is converted into various organic compounds, such as amino acids. Thirty different compounds have been identified in the roots of pumpkin. Half of the material which reaches the roots from the leaves is returned upward to other plant parts.
Circulatory System

This conception of a circulatory system in plants is significant and has modified the studies of scientists in this field. Low root temperature may block movement appreciably. Studies with sugar cane show that sucrose may move at the rate of 60 to 70 centimeters per hour in the plant, and that it may take no longer than 20 to 40 minutes for products of photosynthesis to reach regions of active plant growth.

Growth under Arid Conditions

In arid regions where water is limited, it has been found, by using radioactive carbon, that growth of a plant is checked when the plant cannot continue to deposit cellulose on the cell walls. This condition is brought about by high osmotic pressure within the cells, which in turn is the result of water shortage. This information provides a new approach to understanding the water requirements of plants, including irrigation.

Soil and Fertilizer Studies

Radioisotopes have been exceedingly helpful in soil and fertilizer studies. Thus, by using labeled phosphorus (P^{32}) it has been found that the percentage of phosphorus taken up by the plant from applied phosphorus fertilizer is greater (48 to 68 percent) than heretofore believed (10 to 12 percent). Further, phosphorus may move very rapidly into the plant and may be found in the leaves 15 to 20 minutes after soil application.

In the matter of placement of fertilizer, applied phosphorus is found in the plant within 2 or 3 days when placement is 3 to 4 cm below the seed, compared to 3 to 4 weeks when applied 5 or 6 cm to the side of the seed.

Soil Temperature

Temperature of the soil markedly affects uptake of certain nutrients. Using radioactive phosphorus it is shown that a reduction of soil temperature from 18 to 20 degrees C. to 6 to 7 degrees C. will reduce phosphorus uptake by half. Using radioactive calcium, it is determined that similar reductions in temperature reduce calcium uptake 40 percent. Heavier soil applications of complete fertilizers (NPK) and foliar
feeding have both been found valuable under these conditions. These findings are of great significance in northern regions where soils are cool. They may influence the northern extension of agriculture appreciably.

Green Manure Crops

The decomposition of green manure crops in the soil and the availability of decomposition products to plants has been studied effectively by incorporating radioactive carbon and phosphorus and other materials in the crop to be studied. In this way valuable information has become available as to the relative value of various green manure crops at different ages and with reference to plant crop needs.

Root Efficiency

When called upon to do so, a single plant root can take up more nutrients than has been commonly appreciated. When a plant is furnished with an adequate supply of phosphorus, for example, a single root will take up to 4 to 5 percent of the labeled phosphorus placed in the soil. However, if the supply of phosphorus is reduced in the plant, this same root may take up twenty to thirty times as much.

Root Distribution

The spread and distribution of roots in the soil is studied effectively with radioactive isotopes. Such studies in the past have depended upon laborious excavations. Now, by placing the same or different labeled materials in different positions in the soil, the position of the roots of the plants can be established.

Root Grafting in Forest Trees

Radioisotopes have given an entirely new concept as to the make-up of groupings of forest trees. It is found that forest trees, such as the pin oak, must be thought of as colonies rather than as groups of individual trees. In fact, the roots of a colony of pin oaks have been found to be naturally grafted together underground so that the root systems of the members of the colony are physically related. Materials may move from one tree to another in this way. Diseases, also, may spread from one tree to another. Spores of the wilt disease of pin oak have
been treated with radioactive silver and radioactive iodine and have been followed from injections in one tree through natural root grafts into another tree. The effective control of this disease is now seen to depend upon removing not only the diseased tree but also those which belong in the colony.

**Foliar Feeding**

Roots are commonly accepted as the principal organs through which plants absorb nutrients, which are then transported to other portions of the plant—stems, leaves, flowers, and fruits. That the reverse of this process could and does occur, namely, the uptake of nutrients by stems, leaves, flowers, and fruits—has long been indicated by certain horticultural practices. Yet only recently has this truth been demonstrated experimentally.

Radioisotopes of the elements commonly applied as fertilizers have made it possible to follow and evaluate the absorption of nutrients by above-ground parts of plants in comparison to absorption by roots. A remarkable efficiency of uptake by leaves and many important facts relative to mineral nutrition and fertilizer use have been revealed.

Radioactive mineral nutrients applied to leaf, stem, and even fruit surfaces are readily absorbed as measured by subsequent assay of non-treated parts. In fact, nutrients have been shown to enter even through the bark of dormant fruit trees.

A proved method is now available for treatment of wounded and injured fruit trees through application of nutrients to the trunk and branches during the dormant and early spring seasons, and the practices of correcting zinc deficiency and applying nutrients by dormant applications is rationalized.

Although nutrients may enter woody plants through the bark, even during the dormant season, it is of more importance that they may enter through the leaves. It is now established that the surface of a leaf is not the impervious structure described in many textbooks. Instead, it is structurally well equipped to absorb materials through both the upper and lower surfaces.

By using isotope techniques it has been demonstrated conclusively that with many herbaceous crops, foliar-applied nutrients can make a significant contribution to the total nutrient needs of the plant. The percentage of phosphorus utilized from applied fertilizer is highest in
foliage sprays—up to 95 percent of the fertilizers applied, in some instances. In fact, the application of phosphorus to the leaves of plants represents the most efficient method of fertilizer placement yet devised.

Typically, many crops, especially fruits and vegetable crops, during normal development pass through critical periods associated with flowering and fruiting when nutrient demands are high and when availability from soil sources is low or at a minimum. It has been demonstrated by the isotope technique that during these critical periods leaves can supplement the function of the roots as nutrient-absorbing organs.

Urea is one of the most useful and well-known nitrogenous fertilizers for leaf application. With some horticultural crops the entire requirement for nitrogen can be satisfied by a few appropriately timed sprays. Radioisotopes provide a specific and sensitive tool to ascertain the rate and extent of utilization and to predict crop tolerance of foliar applications of urea nitrogen. The first step in the utilization of the nitrogen in urea by the leaves of plants presumably is hydrolysis by the enzyme urease, splitting the urea molecule and giving ammonia and carbon dioxide. As a measurement of urease activity, and thereby the rate of hydrolysis and possible utilization of urea applied to the leaves of horticultural plants, radioactive C¹⁴ urea may be employed and the rate of evolution of radioactive carbon dioxide determined.

Such highly mobile elements as nitrogen, phosphorus, potassium, and rubidium, when applied to aerial plant parts are readily translocated both upward and downward, and at a rate comparable to that which follows root absorption.

On the other hand, such materials as calcium, strontium, and barium do not move easily from the absorbing plant part; and downward transport is negligible. From this it now becomes apparent why foliar sprays of calcium are practically useless to the roots in contrast to such mobile materials as phosphorus and potassium.

Zinc and iron deficiency disorders in citrus are now controlled by applying spray containing zinc and iron to above-ground parts. Magnesium deficiency in celery is dramatically controlled with 7 pounds of magnesium sulfate in 100 gallons of water applied at weekly intervals for 6 or 7 weeks, where soil applications give no response.

The entire nitrogen requirements of an apple tree for the season can be supplied by foliar sprays of urea. In the pineapple industry, 75 to 80 percent of the nitrogen and 40 to 50 percent of the phosphorus
and potassium are applied with great exactness throughout the life of the plant by foliar sprays. In addition, flowering and fruiting are controlled by foliar sprays of the hormone-like material, naphthalene acetic acid, so that pineapple production is placed upon an assembly line basis with fields ripening in succession as desired. All of this has been aided by the use of radioisotopes.

**Herbicides**

Weed control involving chemical plant regulators is one of the recent important discoveries in agriculture. The molecules involved and the changes within the plant and in the soil from microbial action are complex. Radioisotopes have given an understanding of how the materials enter the plant, how they move within the plant, and how they act. For example, the effectiveness of post-emergent herbicides is dependent upon foliar absorption, whereas the effectiveness of pre-emergent herbicides is dependent upon soil application.

Studies with the well-known selective herbicide 2,4-D, using radioactive isotopes show that the chemical is distributed throughout the plant within 24 hours, thus helping to explain its effectiveness and mode of action. An insecticide known as Systox has been shown, by the use of labeled phosphorus, to depend for its potency upon the fact that it is metabolized in the plant into a product which is more toxic than the initial compound itself.

**Other Research Areas Using Radioisotopes**

**Yeast**

The physiology and metabolism of yeast in fermentation of malt wort has been explored with radioactive carbon and improvements made in the process as a result.

**Plant Regulators**

The entry, distribution, and mode of action of plant regulators used in preventing pre-harvest drop of fruit and in chemical thinning of blossoms from fruit trees have been studied using various radioactive isotopes. From this have come improvements in practices which have helped to make such treatments commercially effective.
Leaching

Since nutrients may enter the leaf, it naturally follows that under appropriate conditions they may be lost from the leaf. This hypothesis has been tested with radioactive isotopes and found to be true. Significant losses of both mineral and organic materials may occur from only 30 minutes of leaching in water. Yields of wheat have been reduced 30 percent from 3 days of leaching by rain during the milk stage of grain development.

If leaching occurs through a leaf while still attached to the parent plant, more material can be removed by protracted leaching than was present originally in the leaf. This helps to explain why nutrients tend to accumulate under forest trees.

Nutrients may also be leached from fruits; the sugars and pigments washed from strawberries during a rainy spell explain the poor color and insipid flavor of fruits harvested during such a period.

Pollination

An interesting effect of pollen and pollen tube content has been revealed by the use of pollen labeled with radioactive phosphorus and sulphur. The contents of the pollen tube may enter into the metabolism of the mother plant, and the effect of a number of repeated pollinations has been observed. The endosperm color in corn is found to be dominant only if a sufficient number of pollen tubes enter the embryo sac. The importance of the amount of pollen and the kind of pollen is now seen to be a matter of study and concern.

The degree of dispersion of pollen in alfalfa has been studied with labeled sulphur and found to be about 9 to 10 meters. Further, only about one-fifth of the pollen observed on the stigmatic surface of a flower was found to be from the same plant; a pollen tube from a foreign plant is about 40 times more likely to fertilize an ovule than a pollen tube from the mother plant.

Spore, Bacteria, and Insect Dispersion

Airborne movement of spores and of bacilli have been followed by using $^{32}$P labeled materials. Labeled mosquitoes have been found to move as far as 7 miles, although the majority remain within one-eighth of a mile from the place where they originate. Labeled grasshoppers
move at a rate of 7 yards per hour. Wireworms and cutworms labeled with Cobalt 60 have been followed underground in the soil and observed to move about 12.5 cm in three minutes. With automatic plotting devices, their movement in the soil has been determined critically. All of this is of great value in control of insects and diseases.

Lake Fertilization

Lakes are wasteful of the phosphorus which enters them, the phosphorus being locked up in the mud of the lake bottom and being not easily available to marine plant life growing in the lakes. Compressed air bubbled into the water sets up an artificial circulation which disturbs the phosphorus at the bottom of the lake and makes it more readily available. Using tagged phosphorus it is shown that such treatment in mid-summer results in "internal fertilizing" of the lake comparable to application of phosphorus fertilizers.

Water Supply

Man-made tritium has been used in the study of the circulatory rates for water in the northern hemisphere. It has been found that one-third of the rain in the Upper Mississippi Valley is from ocean water and two-thirds is from re-evaporated surface water. About one meter per years is from the ocean. Ground water from wells dug for normal use is older than 50 years. Hot springs are rain water stored for a relatively short period. Such information is of great value in understanding underground water supplies, their depletion by pumping, their replenishment, and their relation to drouth.

CA Storage

Fruit, grain, and silage are stored in artificial atmospheres of controlled carbon dioxide and oxygen levels. By the use of C14 labeled carbon dioxide it has been found that the effect of carbon dioxide in the controlled atmosphere is not alone in that it retards the respiration rate and delays deterioration. In addition, the carbon dioxide is actually used by the fruit in synthesizing various organic compounds which enter into its composition and alter it. In the case of apples, the acid-sugar ratio is reduced, the flavor improved, and the shelf-life extended.
Using C\textsuperscript{14} labeled carbon dioxide, the processes going on within fruits have been studied. Thus it has been shown that carbon dioxide may develop in the core of certain fruits from the intensive respiration of developing seeds. This carbon dioxide may then diffuse to the surface of the green fruit where it is used in photosynthesis. The mechanism in this way removes excess carbon dioxide and aids in maintaining the supply of oxygen essential to seed development.

**Losses to Agriculture From Insects, Diseases, and Weeds**

The loss caused by insects to agriculture is estimated at 4 billion dollars a year for the United States. ("Losses Caused by Insects" by G. J. Haeussler in *Insects—The Yearbook of Agriculture for 1952*, pages 141-146. 1953.)

The loss caused by plant diseases is estimated at 3 billion dollars a year for the United States. ("Three Billion Dollars a Year" by Jessie I. Wood in *Plant Diseases—The Yearbook of Agriculture for 1953*, pages 1-9, 1954.)

The loss from weeds in the United States for a year is estimated at 4 billion dollars. ("Weed, Grass, and Bush Control Handbook." Dow Chemical Company, Midland, Michigan, 1958.)
INVESTIGATIONS OF SULFUR ON PLANT-SOIL RELATIONSHIPS

S. C. Fang and M. E. Harward
Oregon State College, Corvallis, Oregon

Investigations on the movement of sulfate in soils and the residual effects of soil sulfur in relation to plant response to applied sulfate have been currently under way at Oregon State College, Corvallis, Oregon. These experiments include soil and plant studies with $^{35}$S-tagged sulfate. Information along this line is needed in the formulation of economical and efficient fertilizer programs. Although the study has practical implications, primary emphasis is being placed on the chemical reactions and other phenomena involving sulfur in soils.

Soils of different series exhibit a marked difference in the retention of sulfate ions against the leaching action of water. The downward movement of sulfate through the soil columns as a function of the amount of water added may well represent an alternate adsorption-desorption process occurring during the percolation of water. The higher the rate of sulfate application to the soil column, the greater the loss of sulfate through leaching, with an equal amount of percolation water. Of the soils tested, the Brown and the Reddish Brown Latosols show an appreciable ability to hold sulfate ions against leaching, as well as its uptake by the root system. These soils also contain much higher free iron and aluminum oxides which may be responsible for the stronger retentive power.

As to the influence of fertilization on the downward movement of sulfate by leaching, a slight increase was observed by phosphate fertilization, while a greater one was caused by liming. Additions of lime and phosphate behaved independently of each other so far as effect on movement of sulfate was concerned. The extent of sulfate movement as influenced by these two factors is dependent on the nature of the soil.

Alfalfa showed significant yield response to sulfate applications on eleven of the sixteen soils studied. Sulfur treatments increased the sulfur content of alfalfa conspicuously. The higher the sulfur content of the nonsulfur treated plant, the closer the yield was to that of the sulfur treated plant. The rate of change in percent yield (yield without sulfur/yield with sulfur $\times 100$) decreased appreciably when the sulfur content of alfalfa approached 0.2 percent.
Significant correlation coefficients were observed between sulfur "A" values (an estimate of available S obtained with isotope dilution technique) and percent yield of alfalfa, sulfur content and "A" values, and sulfate content in soil (extractable with Morgan solution) plus sulfur release and percent yield. A sulfur "A" value of 20 pounds per acre in Oregon soils may be taken as a sufficient level for growing alfalfa under the experimental conditions used. Yield increases due to sulfur additions were not observed on soils with "A" values higher than 20.
RADIOISOTOPES IN AGRICULTURE: SOIL AND WATER

Harris M. Benedict, Director of the Agricultural Research Center, Stanford Research Institute
Menlo Park, California

Introduction

At present, agriculture crop production is almost completely dependent on soil for its cultural medium. A few agricultural industries use water and sand culture techniques on a commercial scale, but there are so few of them, they can be ignored so far as the purposes of this report are concerned.

Soil is important in many ways. It provides a solid material in which plants can imbed their roots and thus provides support for upright growth. It provides a medium in which water, which is so essential to plant life, can be stored and made available to the plants without completely submerging or drowning the roots. It contains the macre- and micro-elements which are essential to plant growth, or if these essential elements are depleted, it provides a medium in which artificially added elements (fertilizers) can be stored and made available to plant growth over a fairly long period of time.

Different crops have different requirements. The ability of a soil to produce a crop depends on the needs of the crop and the manner in which the soil performs the functions listed above. The soil's ability to perform these functions is dependent upon the physical and chemical properties of the soil in question. The chemical and physical properties vary a great deal from soil to soil.

Water is also essential to plant growth, not only because it itself is essential for various life processes, but also because it brings the essential elements into solution or into the state that plants can utilize. Soil and water effects in agriculture are closely related, and any factor which affects one will probably affect the other as far as its functions in crop production are concerned.

Water Supply

There is one outstanding exception to the above rule—that is, the total amount of water available during a growing season. It is extremely important to know how much water will be available for crop production.
In areas relying entirely upon rainfall for water, the farmer is dependent on weather predictions or forecasts, but in many irrigated sections the farmer relies on the amount of water on nearby or remote watersheds that has accumulated as snow during the previous winter.

It is important to know how much water is contained in the snow pack so that irrigation allocations and schedules can be planned for the following year. If the water supply is less than normal, then perhaps not so many acres will be planted or a crop requiring less water may be grown.

In the past, the amount of water in snow packs was determined by weighing the water in a core drilled from the snow pack from surface to ground. This involved a trip on skis to the proper location, taking a core which might be well over 15 feet long, melting the snow, and weighing or determining the volume of the water. Using radioactive cobalt at ground level and an instrument that is sensitive to gamma rays, the weight of the snow in a core can be determined by the reduction in intensity of the rays striking the receiver. Since this reduction is related to the mass of material between the source and the receiver and not necessarily the depth, a direct reading can be obtained. Instruments are constructed to read directly in inches or feet of water. Since it can all be carried out electrically, the recorder can be placed at ranger stations or other easily accessible places, and the water available for irrigation from a watershed can now be reported without stirring away from the fireside.

This method has resulted in more accurate predictions of available moisture at regular intervals independent of the weather. During the spring and summer, the same instruments indicate the rate of melting. The results of this use of radioisotopes have been more efficient use of water and lands under irrigation and less crop failures as a result of variation in water supply on the watersheds.

In addition to using surface runoff for irrigation purposes, underground reservoirs are tapped by wells and pumps. With the development of techniques using radioactive hydrogen or tritium which has a half life of thirteen years, it has been possible to estimate the age of underground waters \( \frac{1}{2} \)-that is, the time elapsed from rainfall to pumping. The elapsed time indicates the distance the water must have traveled and from this the ultimate source can be determined. Better estimates of available water, based on the rising or falling of water tables, can be made. A similar technique is used to determine routes of underground streams and, from these possible sites, for underground dams that have become so important in increasing subterranean water sources.

\[1/ \text{Figures in parentheses refer to literature cited.}\]
Soils

Physical Properties of Soils

The bulk density of a soil serves as an index of the mechanical impedance of the soil to penetration by plant roots (27). Methods to determine this characteristic have involved the rate of penetration of liquids into the soils (5) and the weight of a given volume of soil (17). The determination of the weight of a unit of volume of a soil sample is the most accurate method not involving radioactivity, but it is laborious and time consuming.

Recently attempts have been made to develop methods using Co$^{60}$ or Cl$^{134}$ (34). The principal involved is the measurement of the backscattering of gamma rays of 1 MEV or more from a source through the soil. The instrument is simply placed on the soil surface and the counting rate measured and compared with a standard such as water. This method has not been satisfactorily perfected, but it does show promise as an aid in measuring the bulk density of a soil (27).

Adequate aeration of the soil has been shown to be important in water uptake, nutrient uptake, and plant growth generally, and thus is one of the most important features of a good agricultural soil (22).

To estimate the rate of aeration of various soils many methods have been devised including oxidation and reduction potentials, tests for ferrous iron, and partial pressure of oxygen in the soil atmosphere. The values obtained with these methods have not correlated with observed plant growth. Diffusion rates of gases through soils have been thought to be indicative of the soil's aeration, and many studies have been carried out using this approach. The earlier ones all used a diffusing gas which differed markedly in molecular weight from the gas in the soil atmosphere (27). This difference meant that some mixing might occur as a result of mass flow rather than diffusion alone. Recently a study has been carried out in which radioactive Co$_2$ was allowed to diffuse through a soil with an atmosphere of stable Co$_2$ which would prevent mass flow, the objection to earlier studies, since the difference in molecular weight of the two gases is relatively small. Thus radioactivity has proved to be a useful tool for studying soil structure (29).

Probably the most important physical property of a soil is its moisture content. In growing crops, especially where rainfall is not or cannot be relied upon, it is desirable to know the moisture content of the soil so that irrigation can be done at the optimal time. There
are several methods available for determining soil moisture, but all have their limitations. They include:

1. Oven drying of collected soil samples
2. Conductivity
3. Resistance to penetration
4. Heat transfer
5. Tensiometers

A soil moisture-measuring device should show a continuous record in simple units that represent the energy with which the moisture is bound to the soil; it should not disturb the soil; it should work in any soil; and it should be sensitive to any form of water present (27). A method involving radioisotopes has been developed for determining soil moisture which meets most of these requirements and yet is much simpler and easier than older methods. The radioisotope method depends on the ability of hydrogen nuclei to convert fast neutrons to slow neutrons. Since water is the principal compound with hydrogen nuclei in soils, reduction of neutron speed in soil is related to its water content.

In actual practice a source of fast neutrons (preferably sodium-beryllium) is placed on the soil surface or in a well in the soil. The fast neutrons radiate out into the soil. When some strike slow hydrogen nuclei, they are converted to slow neutrons and deflected back toward the sensing agent which is close to the sodium-beryllium source. Slow neutrons induce radioactivity in certain elements, particularly boron, and the radioactivity can be measured. From this measurement, the moisture content of the soil can be directly determined (6, 31, 33). This method is fairly accurate and simple, but at present does not indicate the force or tension by which the moisture is held to the soil particles.

Other methods using radioisotopes to determine soil moisture have been developed, but they involve transmission of neutrons or gamma rays between two holes in the soil. The chief difficulty of older soil moisture methods, that of digging holes, is not eliminated.

**Chemical Properties of Soils**

There are essentially two ways in which the chemical properties of soils may affect the production of agricultural crops. They are the actual chemical make-up or percentage of essential elements present in the soil and the chemical constituents present, which in themselves are not essential to plant growth, but may affect the availability of the essential elements to the growing crops.
Usually the actual amount of macro-elements—i.e., N, P, K, Ca, Mg, and S—is the controlling factor as to whether or not there is enough of any one element for adequate growth. Influences of other compounds on the availability of these are of minor importance to crop production with the possible exception of phosphorus. In the case of the micro-elements, however—i.e., Fe, Mn, Zn, Mo, B, Cu, and Cl—very often there is sufficient quantity in the soil to adequately support plant growth, but it is not available to the plant because of other soil properties.

It is of the utmost importance to estimate the availability of at least the soil borne macro-elements to crops. There are several methods that have been developed for doing this in the laboratory, the greenhouse, or the field. Radioisotopes have been effective in improving the accuracy of these methods.

For the most part, laboratory tests have consisted of analyses of weak acid extracts of the soil or the soil solution. Their results gave no indication of the total amount of an element available to the crop, but only of the ability of the soil to release the ions at any one time. Many radioisotopes have been used in laboratory investigations with soils, but only \( P^{32} \) and \( Ca^{45} \) have been used for quantitative estimates of the amount available in the soils (11).

The procedure is based on the assumption that when \( P^{32} \) is added to a soil water system, the following reaction will occur.

\[
P^{32} \text{ solution} + P^{31} \text{ solid} \rightarrow P^{32} \text{ solid} + P^{31} \text{ solution}
\]

\[
\frac{P^{32} \text{ solid}}{P^{32} \text{ solution}} = \frac{P^{31} \text{ solid}}{P^{31} \text{ solution}},
\]

\( P^{31} \) solid is the P on the solid that has come to equilibrium with \( P^{32} \). Then the \( P^{31} \) on the solid that has equilibrated with \( P^{32} \) can be calculated by determining the \( P^{31} \) in the solution and the amount of \( P^{32} \) left in solution. Since the amount of \( P^{32} \) added is known, the amount on the solid can be calculated by difference (21). The results of such an analysis are independent of water soil ratio over a fourfold range. The technique also appears to be independent of the amount of phosphorus added as \( P^{31} \) carrier. The results are somewhat dependent on time as a day should be allowed for equilibration.

The amount of exchangeable calcium in soils has also been determined using a similar technique (4).
In the past, measurements in the greenhouse have involved growing plants under a standard set of conditions in soils to which different amounts of the element in question were added, and then measuring the growth of the plant. Such a method involved growing plants under severe nutrient deficiencies in abnormal conditions. Extrapolations that have not been universally accepted, were made from the data.

Using radioactive phosphorus, it was noted that the nutrient level in the soil had a direct effect on the proportion of the nutrient derived from the fertilizer. This relationship may be expressed as follows:

\[ A = \frac{1-y}{y} B \]

where

- \( A \) = amount of available nutrient in the soil
- \( y \) = proportion of nutrient in the plant derived from the fertilizer
- \( B \) = amount of fertilizer nutrient applied

Thus the method of determining \( A \) simply involves the introduction of a known quantity from a standard source of the nutrient under consideration (\( B \)), growing the desired crops, determining the proportion of the nutrient in the plant derived from the standard (a radioactive source \( [y] \)), and then calculating \( A \) by use of the above equation. It is, of course, essential that the nutrient in the soil and fertilizer be equally available to the plant (9, 12, 36).

The isotopic technique has the following advantages over nonisotopic procedures.

1. "\( A \)" is not dependent on the amount of nutrient applied. Thus only one determination is necessary instead of many to derive a curve.
2. The plants do not have to be grown under abnormal conditions of severe nutrient stress.
3. The value obtained is not an extrapolated one and thus the error of estimate is not increased.
4. The amount of plant growth does not affect the results.

Most of the work along this line has been done with phosphorus, however similar techniques are available for other elements, such as: sulfur (1), calcium (13), zinc (24), iron (15), and manganese (28).
Field measurements are carried out in the same manner as the other tests both isotopically and nonisotopically except that an entire field is used. These studies are not precise because of the many variables involved. However, radioisotopes can help in the usual objectives of field tests, i.e., the evaluation of a quick soil test or the better definition of the soil-plant relationship as it actually occurs in the field.

The previous section has dealt with plant nutrients as they occur in the soil. It is common practice to add to the soil, fertilizers or chemicals which will increase crop production. Radioisotopes have been an important aid in determining how to obtain the maximum value from the nutrients applied. The following are some of the types of studies that have been carried out and examples of each.

By the use of radiophosphorus, it was shown that superphosphate and ammonium phosphate provided about the same amount of phosphorus to various crops and that tricalcium phosphate supplied much less phosphorus than the other two (16, 19, 25, 30).

A great many studies have been conducted to determine where in the soil, fertilizers should be placed to be most efficiently used. For example, it was found that on a sandy loam, surface-applied phosphorus was utilized to a greater extent by alfalfa than that placed 3 and 6 inches deep (18, 19). Peanuts have been found to require abundant calcium in the fruiting zone (2).

Studies with radioisotopes have borne out observation and experimental evidence that crops differ in their ability to obtain nutrient elements from similar sources. For example, buckwheat and alfalfa were found to take up considerably more phosphorus from the same soil than beets, crotalaria, oats, or perennial ryegrass (10).

Use of radioactive fertilizer elements have shown that a greater proportion of the applied nutrient is used during the early stages of growth (23).

One of the problems confronting edaphologists for years has been the movement of nutrients in the soil especially during leaching processes. Studies involving radiophosphorus have shown very little downward movement of applied phosphorus even after heavy application of water (14). Studies with calcium, however, show a gradual movement downward with leaching (3).
Radioisotopes have been of special benefit in increasing our understanding of the factors affecting the availability of the so-called micro-elements in the soil. Very often they are in abundant supply, but some particular chemical characteristic of the soil may make them relatively unavailable to the crops. The literature on the use of radioisotopes in this phase of agriculture has been reviewed recently (32). A few examples of the types of investigation with various micro-nutrients follow.

Chlorosis due to lack of iron is common on highly calcareous soils in the western United States. After many investigations, it was finally demonstrated that among other factors the bicarbonate ion concentration was an extremely important one in determining whether chlorosis would develop (26). Phosphorus concentration is also of great importance.

That zinc availability varies greatly from soil to soil is well known, but the factors affecting this availability are not well understood. The use of radioactive zinc has been of great aid in gaining a better understanding of this problem. Data indicate that the relative retention of zinc in soils can be shown as follows (24):

$$H > Zn > Ca > Mg > K$$

Use of Mn⁵⁴ has shown that after 4 to 5 months, 50 percent of the manganese added to the soil is still available to the crops (12).

This element has been found to be fixed more strongly in acid than in alkaline soils, a reversal of the usual situation with micro-elements (8).

All of these studies have been of tremendous assistance to farmers. Laboratory or greenhouse tests can quickly indicate the amount of certain elements that are available per acre of soil under consideration, and from this, the amount of this element that will have to be applied as a fertilizer. Information is now available on how deep it should be applied, how far from the plant rows, what time of year, or at what age of the crop. Thus, the greatest or most efficient use of the fertilizer applied can be made.

**Biological Properties of Soils**

In addition to the crops, soils also contain a micro-flora and -fauna which directly affect agricultural production. They include bacteria, fungi nematodes, earthworms, etc. Some of them are beneficial
such as nitrofying bacteria and earthworms. Most of them are, however, harmful as they are responsible for soil-borne diseases. A great deal of consideration has been given to the possible use of radiation from various radioactive sources as soil sterilization agents. This has not reached a practical stage as yet because the dose required to sterilize to sufficient depths is quite large (20).

However, if such a method of soil sterilization is made practical, it could affect agricultural crop production radically. The need for crop rotation to allow certain organisms, which attack specific host plants, to die out before replanting may be eliminated. It might be possible to inoculate soils with beneficial organisms that will last for some time, providing that radioactive materials could kill off organisms that are antagonistic to the beneficial ones (35).

**Summary and Conclusions**

A survey of the investigations in which radioisotopes have been used indicates that these materials have greatly added to our knowledge of the inter-relations between crop production, water supply, and soil characteristics. The contribution of radioisotopes has been to increase the facility with which certain information is obtained, to increase the accuracy and reliability of the results, and occasionally, but not often, to obtain information that could not be obtained without them.

With gages using radiocobalt or similar gamma ray emitters, it has been possible to greatly increase the accuracy of the estimates of the water in mountain snow packs. Using natural or added tritium, it has been possible to study the flow of underground waters. As a result, much more accurate estimates can be made of the available water for crop production purposes in both runoff and pump irrigation areas. More efficient and economic farm and water planning has resulted in savings since irrigation water can be more efficiently proportioned, and in cases of real shortage, the type of crops grown could be changed to meet the emergency.

The physical properties of a soil that affect crop production, aside from soil temperature, are soil moisture, soil aeration, and the physical restriction imposed on root and shoot development.

Through the measurement of the moderation of neutrons by hydrogen nuclei in soil and its accompanying backscattering, methods have been developed for determining soil moisture which match most of the capabilities of established methods, yet are much easier to carry out. Of all
the physical properties of soil, moisture content is the most important. Any procedure which facilitates and broadens the use of this determination is extremely valuable. A farm operator will be able to irrigate at the optimum time for plant growth without wasting water. In other words, the farmer can make the most efficient possible use of the water available.

The method of determining soil aeration has recently been facilitated by the measurement of diffusion rates of radioactive Co\(^{2}\) through soil saturated with nonradioactive Co\(^{2}\). Impedence to root and shoot growth has also been estimated through the use of gamma rays in determining bulk density of the soil. These procedures will be an aid in evaluating a soil for a particular crop. While these procedures for determining physical properties of soils show promise, none of them have yet reached a stage where they are commonly used. The broader use of such analytical techniques by farm operators will, in the future, contribute significantly to increased farm productivity.

The chemical properties of a soil primarily govern the amount and availability of nutrients to growing plants. Radioisotopes have made their biggest impact in agriculture, from the soil standpoint, in the determination of the amount of nutrients available for plant growth in the soil, and the method, placement, and time of application of supplementary elements or fertilizers. The accuracy and ease of estimating the amount of certain essential elements available to growing crops has been greatly enhanced through the use of radioisotope tracer techniques. Laboratory, greenhouse, and field measurements can be made. In a similar manner, studies using radioisotopes have shown where fertilizers should be placed, what time in the growing cycle they should be applied, the age at which the plant absorbs the greatest quantity, and how much leaching or movement may take place in the soil after application.

Studies with the so-called micro-nutrients have shown under what soil conditions they may be unavailable to plants and in what ratios they should exist in the soil. These ratios apply between micro-nutrients and between micro- and macro-nutrients. Some of the micro-elements whose availability in soil have been studied are boron, chlorine, cobalt, copper, iron, manganese, molybdenum, and zinc. Investigations have indicated that cobalt may not be essential for plants, even though it is essential for animals.

Soil-borne organisms, which adversely affect the growth of crops have been a problem to growers for years because of the difficulty of destroying them. Ionizing radiations because of their penetrability and lethal effect offer a possible means of soil sterilization on a large scale. However, practical methods have not yet been developed.
The actual savings in dollars which has resulted from the use of radioisotopes in soil and water investigations is hard to estimate. The greatest interest has been in phosphorus and if, as a result of knowledge gained, the phosphate fertilizer bill has been reduced 10 percent, a not unlikely figure, then this item alone has resulted in a savings of $15,000,000 a year for at least the last 5 years.
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Appendix B

TABULATION OF DATA FROM QUESTIONNAIRES
AGRICULTURAL EXPERIMENT STATION RESEARCH PROJECTS
USING RADIOISOTOPES

A survey was conducted among the users of radioisotopes in agricultural research in order to ascertain the different applications of isotopes in the fields of research, the isotopes used, the number of persons using them, and the potential benefits from such research. All Agricultural Experiment Stations of the land-grant colleges were contacted and asked to provide the described data. A sample questionnaire is on the following pages.

Of the 43 Agricultural Experiment Stations using isotopes in research, 36 responded; data from most were usable and complete enough for the analysis found in Section V and the tabulation of projects on the following pages.

The tabulation is of 111 selected projects underway at 24 stations with a Roman numeral to represent each station. The 111 projects represent a good cross-section of projects that use radioisotopes in agricultural research.
April 17, 1959

Stanford Research Institute is conducting a study for the Atomic Energy Commission directed toward estimating economic benefits and advantages obtained from all research in agriculture involving radioisotopes.

The undersigned are assisting in this study, particularly in matters pertaining to an evaluation of the nature, scope, and benefit of the research being conducted in this field by the Agricultural Experiment Stations.

We realize that the estimating of current and future benefits of this research involving radioisotopes is extremely conjectural. However, this information as requested in the attached circular, is vital to the Commission's impending evaluation of its support program of agricultural research and we hope very much that you will make some educated guesses of these benefits where appropriate.

Your help in supplying this information not later than April 27 will be much appreciated. No information obtained from any one institution will be published.

A postpaid and addressed envelope has been enclosed for your convenience.

Sincerely,

Harold B. Tukey
Michigan State University

Cyril L. Comar
Cornell University

P.O. Box 672
Michigan State University
East Lansing, Michigan
In order to assess the Scope and Nature of Present and Future Research involving Radioisotopes, research projects have been categorized according to the funds allocated to them for salaries and wages as follows:

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Projects</th>
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<tbody>
<tr>
<td>$2,500 and less</td>
<td>1</td>
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<tr>
<td>$2,500 to $4,999</td>
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<td>$5,000 to $9,999</td>
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<td>$10,000 to $19,999</td>
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<td>$20,000 to $29,999</td>
<td>5</td>
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<tr>
<td>$30,000 and over</td>
<td>6</td>
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</tbody>
</table>

Record below in columns (1), (2), and (3) the appropriate category numbers shown above; for example, $9,000 spent in one year on 3 projects for study of fertilizer uptake would fall in category 3. The information requested in column (4) is self-explanatory.

<table>
<thead>
<tr>
<th>Fields of Research</th>
<th>(1) Research Expenditures in FY 1958-59</th>
<th>(2) Research Expenditures Planned for FY 1959-60</th>
<th>(3) Research Expenditures Which Would Be Made If Proper Support Were Forthcoming in FY 1959-60</th>
<th>(4) Indicate Radioisotope(s) Used (if readily available)</th>
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<tbody>
<tr>
<td>I. Soils and Water:</td>
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<tr>
<td>1. Irrigation:</td>
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<td>Water source</td>
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<td>Measuring device</td>
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<td>Other</td>
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<td>2. Soil composition:</td>
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<td>Aeration</td>
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<td>Structure</td>
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<td>Mineral and org. make-up</td>
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<td>Other</td>
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<td>3. Chem. analysis of soil:</td>
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<td>Major elements</td>
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<td>Availability</td>
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<td>Other</td>
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<td>4. Organic decomposition:</td>
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<td>Temperature</td>
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<td>Biol. envir. factors</td>
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<td>5. Nutrient req. and supply (fert):</td>
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<td>Form</td>
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<td>Placement</td>
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<tr>
<td>Uptake</td>
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<tr>
<td>Leaching (movement)</td>
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<tr>
<td>Sterilization</td>
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- $2,500 to $4,999 - 2
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- $5,000 to $9,999 - 3
- $30,000 and over - 6

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</tr>
</thead>
<tbody>
<tr>
<td>II. Plant--Physiology, Genetics Cytology, Pathology</td>
<td>1. Uptake and loss of water and nutrients (incl. plant regulators) by roots</td>
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<td></td>
<td>Uptake and loss of water and nutrients (incl. plant regulators) by &quot;nonroot&quot; parts</td>
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<td>2. Movement of materials within plant: Water</td>
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<td>Nutrients</td>
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<td>Manuf. products</td>
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<td>3. Chemical composition: Leaf and tissue analysis</td>
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<td>Hormones</td>
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<td>4. Synth. and degradation of materials within plants: (incl. enzym. studies) Respiration</td>
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<td>Photosynthesis</td>
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<td>Rate of turnover</td>
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<td>Protein</td>
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<tr>
<th>Funds Allocated</th>
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<td>$30,000 and over</td>
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</table>

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<tr>
<td>II. Plant--Physiology, Genetics Cytology, Pathology (cont.)</td>
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<td>4. Synth. and degradation of materials within plants: (incl. enzym. studies) (cont.)</td>
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<td>Fat</td>
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<td>Latex, nicotine, etc.</td>
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<td>Enzymatic processes</td>
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<td>5. Genetics and cytology:</td>
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<td>Mutations</td>
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<td>9. Mechanism of action:</td>
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<td>Fungicides</td>
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<td>Growth substances</td>
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<td>10. Post harvest physiology</td>
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<td>11. Handling and storage</td>
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<td>12. Other</td>
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<tr>
<td>IIIA. Animals--Physiology, Genetics, and Pathology:</td>
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<tr>
<td>1. Nutrition:</td>
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<td>Management problems</td>
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<td>Requirements</td>
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<td>Deficiency symptoms</td>
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<td>Utilization of nutrients</td>
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<td>Vitamins, tranquilizers</td>
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<td>Efficiency study</td>
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<td>2. Skeletal physiology</td>
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<td>3. Genetics and cytology:</td>
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<td>Chromosome studies</td>
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<td>Microorganisms</td>
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<td>Physiology disturbance</td>
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<td>Insects (pests)</td>
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<td>6. Metabolism and secretion:</td>
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<td>Minerals</td>
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<td>6. Metabolism and secretion (cont.)</td>
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<td>- Lactation</td>
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<td>- Renal functions</td>
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<td>7. Endocrinology</td>
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<td>IIIB. Entomology:</td>
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<td>1. Insect dispersal</td>
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<td>2. Population studies</td>
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<td>5. Biosynthesis</td>
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<td>6. Insect control:</td>
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<td>- Direct control by radiation</td>
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<td>- Insecticides</td>
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<td>- Insecticidal dispersal</td>
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<td>7. Longevity</td>
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<td>1. Diagnostic application</td>
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<td>3. Study of disease processes:</td>
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<td>Infectious diseases</td>
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<td>Pathological aspects</td>
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<td>4. Pharmacology</td>
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<td>IV. Engineering and Mechanical Processes:</td>
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<td>2. Time and efficiency studies</td>
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Fill in the following information about your Experiment Station

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(1) Number of professional personnel on the staff in Physical and Biological Sciences

(2) Number of professional personnel on the staff in Physical and Biological Sciences working with radioisotopes (part time and full time)

(3) What is the approximate full-time equivalent of all time spent by the professional staff under (2) (full-time equivalent is the summation of the fractions of the time spent by each professional staff member in working with radioisotopes)

169
ESTIMATING ECONOMIC BENEFITS TO AGRICULTURE
FROM RESEARCH INVOLVING RADIOISOTOPES

In order to obtain an estimate of economic benefits to agriculture which either have resulted, or could result from research involving radioisotopes, it is requested that you list below projects carried out (current and completed) by your Experiment Station which appear to have possible economic implications for commercial agriculture. With each project listed would you also give the estimated economic benefits in whatever form they have been presented in the annual progress reports of the projects concerned or in your Station's annual report. Economic benefits may be defined as those achieved by increasing money yield per acre as a result of new products, reduced unit cost of production, or improved quality of the product. These benefits may be expressed on a per-acre or per-unit-of-product basis, or on state or national basis.

In those cases where the results of a project obviously have commercial implications but none are listed in the progress reports, please feel free to use your own judgment to make general approximations of possible benefits in whatever form seems appropriate to you for a particular project.

In describing the projects, state the crop or farm animal involved, as well as the insect, pest, disease, or soil problem, etc.

1.

2.

(continued on next page)
ESTIMATING ECONOMIC BENEFITS TO AGRICULTURE
FROM RESEARCH INVOLVING RADIOISOTOPES
(Continued)

3.

4.

5.
I. 1. Cause of variability in response to herbicides increased understanding of the factors affecting the absorption, translocation, and degradation of herbicides.

2. Isotope studies were used to establish pathways of biosynthesis of various compounds in animals. This aids in a better understanding of animal nutrition.

3. Residual value of various phosphate fertilizers. This experiment was conducted using cotton as a test crop. Radiophosphorus uptake data substantiated data obtained by yields showing that phosphates do vary in residual value. Such information is used in calibrating soil test for phosphorus. Phosphorus fertilization based on reliable soil test could save the farmers of this state over a million dollars a year.

4. Availability of raw phosphates. These tests were conducted in the greenhouse to study soil characteristics in relation to availability of rock phosphate. The use of the proper source of phosphorus could increase the income of farmers of this state by several million dollars.

5. a. Metabolism, stability, and residues of organo phosphate insecticides in mammals, plants, and insects. These studies will result in (1) increased public safety, (2) improved quality of crops, and (3) better insect control.

b. Resistance of insects to insecticides. These studies will result in cheaper and more effective insect control.

II. 6. A study of intestinal transit and absorption of radioactive minerals and the role of vitamin D in intestinal absorption in the domestic fowl.

7. Fertilizer placement and fertilizer material studies. The radioactive work has been conducted with phosphatic materials. In this state in 1956, there were 8,500 tons phosphates-containing materials sold. The studies are concerned with the increased efficiency of these materials valued at approximately $750,000. The net benefit may be 20 percent of the fertilizer value annually.
8. Phosphate fertility research. This phase of the work has to do with evaluation and effective use of phosphate. The studies have been conducted with sugar beets, barley, potatoes, and alfalfa. The estimated value of these crops (irrigated only) has been calculated to be $98 million in 1957. The proper use of phosphate could increase the value of beets, potatoes, and barley by 20 percent or more and the value of alfalfa by 50 to 75 percent. The total economic increase would be $32 million or more annually.

9. A study of plant nutrition as affected by aeration is also another of the radioactive studies. P$^{32}$ is used in the study. The economic evaluation is very difficult to assess as the study is currently in the fundamental stages. Presumably, as the result of the studies crop yields will be increased. It is hoped that such increases will be of the order of 10 to 20 percent for irrigated crops. Certain crops, such as sugar beets, alfalfa, and vegetables, may be more sensitive. Total increase might eventually be 15 to 25 million dollars.

10. High mountain disease of cattle causes the death of approximately 0.5 percent of cattle grazing at high altitude. Use of isotopes may enable comprehension of the disease and may result in control.

11. Experimental right heart failure in swine enables study of the disease in laboratory animals for more comprehension.

III.

12. Soil organic matter. The transformations made in nucleic acid derivatives by micro-organisms of the soil. These studies could reveal enzymatic reactions significant in this biologically important class of compounds and the formation from soil organic matter of compounds influential in crop growth. Green manuring commonly increases yields 10 to 20 percent.

13. Tip burn of potato foliage. The proof that this disorder is caused by Ca deficiency and remedied by foliar applications. Some formulations of Ca reduce, others do not affect, the incidence of tip burn. Ca$^{45}$ may reveal the true cause of the disease and a mechanism of control. The disease probably causes a 5 to 10 percent reduction in yield of potatoes.
14. Biochemistry. $^{14}C$-labeled sugars are being used to detect the products of the respiration of carbohydrates in the tobacco leaf when inhibitors of the enzyme glycolic acid oxidase are also present in the tissue.

15. Biochemistry. The biosynthesis of aromatic organic acids in the potato tuber is being examined with the aid of $^{14}C$-labeled aromatic amino acids as a preliminary to the examination of analogous reactions in the tobacco leaf.

16. Biochemistry. The nature of the enzyme mechanisms which are involved in the transformations of three-carbon organic acids in the tobacco leaf are being examined with the aid of $^{14}C$-labeled acids.

17. Biochemistry. An examination is to be made with the aid of $^{14}C$-labeled sucrose of the mechanism whereby fructose condenses with deoxyglucose in the tobacco leaf to form a disaccharide.

IV. 18. Small grain improvement by breeding and selection. New varieties with crown rust resistance selected in irradiated oats. A greater degree of self-fertility induced in rye by irradiation. The oat is a superior variety. In addition, this variety and other selections are superior breeding stocks. Difficult to estimate value on national basis—could easily be millions of dollars.

19. Nutrition and physiology of the peanut. Established that downward movement of calcium from plant to developing peanut is inadequate for fruit development and that calcium must be applied to fruiting area for maximum yields. National returns to growers of millions of dollars.

20. Plant improvement with gamma radiation. Southern peas, beans, cantaloupes, pangolagrass, lawn and turf grasses, lupines, green foliage plants, small grains, chrysanthemums, and woody ornamental shrubs. Possible benefit—millions of dollars to this state's ornamental and nursery industries alone.

21. Citrus nutrition studies. Tagged chelated minor element compounds used in mineral deficiency studies of citrus. Correction of iron chlorosis of citrus alone has resulted in savings of thousands of dollars to this state's citrus growers.
22. Last week at the Spring Meeting of the Directors of Agricultural Experiment Stations of the Southern Region the suggestion was made to Dr. Charles Grey of the State Experiment Station Division, ARS, Washington, that the SESD supply to your group the recent compilation of current research by the USDA and Federal Grant Research at the States on radioactivity.

Projects listed above supplement the SESD list and cover only those which either have had economic benefits or appear to have such potential. Isotopes or irradiation is now being used on 35 projects or 1/10 of the total number of projects at the Florida Station.

V. 23. The role of mineral elements in poultry nutrition. An increase in feed conversion of 0.1 of a pound of feed would mean $3 million a year in this state.

24. Breeding agronomic and horticultural crops and forest trees. (Corn, small grain, forage grasses, peaches, peppers, pine trees.) Improved varieties of any of these could mean millions of dollars per year to this state's agriculture.

25. Comparative studies on uptake, translocation, and metabolism of 2, 4, D and 2, 4, 5, T in certain species of hardwood and pine. Efficient hardwood control could mean several dollars per acre on piedmont forest production. Easily $3 million to $5 million per year.

26. Effect of soil moisture on nutrient absorption in plants. (Pine, hardwoods.) Efficient fertilization of pine production might mean nearly as much as hardwood control. $3 million to $5 million.

VI. 27. Experiments on fat synthesis in animals were started in 1958. It is too early to estimate any economic benefits from these studies.

VII. 28. Plant nutrition. Radioisotopes have been a very useful tool to study the fundamental nutrient requirements and to evaluate the role of each element in the various plant functions.

29. Livestock nutrition. Here again as in plants this offers a very useful tool to further the fundamental work in these
areas. It is almost impossible to assess the potential value that may be derived directly or indirectly.

30. Plant and animal diseases. Evaluation of the specific mode of action of herbicides, insecticides, and other materials on the plant or animal, as well as the insect or organism, has been materially speeded up by this very useful tool. It should and will be used much more extensively in these areas.

VIII. 31. Project involved availabilities of phosphorus in various soils. No economic benefits were estimated. Approximation of research benefits in terms of fertilizer savings on this state's farms could run to millions of dollars.

32. This project involved the study of nutrition of mites feeding on plant material. No estimate made of possible dollar benefits.

33. Project involved study of relationship between copper and calcium in sheep nutrition. No approximation of dollar benefits were made. In terms of state and national significance this would mean millions of dollars.

IX. 34. The most significant contribution from research involving radioisotopes conducted at the Kansas Station, has resulted from studies of the mode of action of insecticides and anthelmintics. The application of these results on a national scale could result in a saving of at least $4 million to the livestock industry.

X. 35. Rot control in cranberries. Radioisotopes have made it possible to devise fungus control measures in the growth of cranberries which will result in about a 20 percent increase in yield and will reduce the present shelf rot from 25 percent to 2 or 3 percent.

36. Soil fertilizer phosphorus fixation and release. Management methods devised as a result of fundamental information obtained should result in reducing the fixation of phosphorus in soils from 80 percent of that applied to a much lower figure. The economic value of this should be great.
37. Thyroid physiology in chickens and turkeys. Fundamental information developed in this project should result in significant financial gains for poultry raisers as a result of the development of strains of birds having appropriate endocrine characteristics, with a resulting greater efficiency in feed utilization. It is estimated that a 20 percent increase in feed utilization might be expected as an ideal.

XI. 38. Economic status is difficult to evaluate since studies were concerned with fundamental plant nutrition and are concerned with:

(a) Cl nutrition of potato plants.
(b) Effect of S:Mg ratios on potato plants.

Other research is concerned with effects of oxygen tensions on enzymes and metabolites. Rats are being sacrificed.

Work is beginning in virology and zoology (arts and science).

XII. 39. Use of P\textsuperscript{32} in fertilizer placement studies has led to methods that will give optimum yield with 30 percent less fertilizer than if previous methods were used. The annual benefit from proper placement on the basis of tonnage used in 1958 would be a saving of $400,000 in production costs.

Soil testing methods have been calibrated, in part, by use of radioisotope dilution values in soils. Judicious use of fertilizers according to reliable soil testing methods is greatly increasing the efficiency of production, but a monetary value can hardly be placed on the benefits derived.

40. C\textsuperscript{14} is being used on fundamental aspects of plant physiology and influence of growth regulating substances on perennial pasture weeds. An understanding of translocation of applied chemicals and their role in other physiological processes may point the way to more effective weed control measures.

XIII. 41. a. Soils: Use of radioisotope techniques in the study of major and minor nutrient elements in soils.

b. Horticulture: Irradiation as an aid in fruit variety improvement.
c. Entomology: The physiology of the mechanism of insecticidal action.

d. Dairy Science: Thyroid activity, its relation to the productive capacities of dairy cattle, heritability and use as a selection index.

e. Sanitation: Biology and biochemistry of waste disposal.

XIV.  

42. Herbicidal residue studies in and/or on forage crops (corn, small grains, and legumes for hay and pasture) and in products from animals fed these forages. (Cl$^{14}$.)

Weeds decrease the yield and quality of this state's $200,000,000 forage crop by at least 20 percent. The yearly $40,000,000 loss of forage due to weeds could be reduced by $10,000,000 through the use of herbicides but detailed residue studies are needed before herbicides can be used to their full potential on forages.

43. An investigation of methods for improving the quality and economy of production of feed crops in the principal soil and climatic regions of this state (p$^{32}$ and C$^{136}$).

Efficient use of fertilizer will save the farmers of New York State millions of dollars a year. Use of radioisotopes has been extremely effective in measuring the influence of rate and method of application upon the uptake of fertilizer materials.

44. Studies on the relative bacterial cleanability of milk-contact surfaces: (p$^{32}$).

These studies are concerned with the removal of bacteria deposited with various soils on milk-contact surfaces. The bacteria were labeled with p$^{32}$ incorporated into test soils, dried down with the soils upon various milk-contact surfaces under highly reproducible conditions, removed by a standard cleaning procedure, and assayed by the agar-submersion, Geiger-counting and autoradiographic techniques. The effect is to point out to manufacturers of farm dairy equipment which materials are best adapted to farm conditions as far as cleaning of these metals or plastics are concerned. Benefits will be from the standpoint of lower bacteria count, higher quality, and better marketability of the milk.
Results can be applied also in the manufacture of chemical cleaning materials.

45. Influence of some environmental conditions and spray additives on absorption of growth substances by apple leaves. (C14.)

Chemical thinning sprays are used on apples and peaches and for control of preharvest drop. Thinning sprays reduce production costs by saving hand labor and promote annual bearing which improves yields. The objectives of the experiment are to: (1) increase production from the use of these growth regulators. It appears that there will be an increase of around 20 percent in annual production. (2) Reduce the hand thinning cost. This varies with the growers. It requires only one man to apply the spray containing the thinner and several to hand thin an orchard. The cost per acre of applying a naphthalene thinning spray is around $5. Hand thinning is as high as $50 per acre.

46. Biosynthesis of proteins. Subtitle: The isolation and characterization of certain soluble liver enzymes and nucleic acids and studies of their roles in protein synthesis. (C14.)

No living organism has been found without protein. At present all we know about protein synthesis, which is fundamental to all living processes, is that nucleic acids are transferred through the genes and chromosomes and form a pattern from which all the proteins which make up the structure of living cells are derived. This is a fundamental piece of research since all growth is based on this process in plants or animals. Eventually as we learn more about this, we can control the efficiency and type of organism and adapt out animals and plants to special uses. It could lead to increased resistance to disease. In the next ten years this study may lead to a 30 to 50 percent increase in efficiency and selection of better producing materials--animals and plants. It also has a definite bearing on cancer research.

47. The phosphorus requirement of dairy cattle. (Ca45.)

As a result of using this isotope to measure the adequacy of phosphorus in the ration, it was found that the phosphorus requirement of dairy calves is approximately 0.22 percent of the air dried ration. This value is approximately
25 percent less than previous studies had indicated and this would represent an economic gain in the feeding of dairy cattle.

48. Mode of Action of 2, 4-Dichlorophenoxyacetic Acid and similar Agents.

To establish the factors which may be responsible for the selectivity of herbicidal chemicals in killing weeds, such as the rate of absorption and translocation, the rate of breakdown and detoxification, the influences of chemicals on photosynthesis, auxin metabolism, pathways of glucose oxidation, acetate utilization and the uptake of nutrients and their utilization.

One of the valuable applications of isotopic technique is the use of labeled compounds in residue studies. This permits rapid and precise determination of the level of chemical residue in the crop. Several such studies in which C14 and S35 labeled herbicides were used have been conducted at this college.

These investigations were conducted with the herbicides endothal, eptam, simazine and atrazine. In all cases these studies enabled the clearance of the chemical for use on crops. Since all of these chemicals are used on row crops, a conservative estimate of the per acre saving because the chemical can be used is $10-$15 per acre. Each of these chemicals will find extensive use, aggregating approximately two million acres. Thus through these studies there is an annual saving of some $20 million to the farmer. The value of the chemicals sold ($1.5 million) is also a benefit to the Agricultural Chemical industry.

49. Relationship of soil properties to chemical reactions and other phenomena involving sulfur.

In Oregon sulfur is a limiting nutrient in one-fourth to one-third of the soils. Some 13,500 tons of sulfur as various sulphates, at a cost of some $60 per ton (approximately $800,000) are used each year. However, it has been established that not all types of soil respond to sulfur treatment. This has been done by the use of isotopic sulfur. It is estimated that conservatively 10 percent of this cost can be saved by applying the knowledge gained through this research, equaling some $80,000 per year.
To investigate physical and chemical properties of 16 Oregon soils in relation to the rate of leaching, the rate of uptake and utilization of CaS\textsubscript{3}S\textsubscript{0}4 fertilizer by plants.

50. The effects of soil temperature and morphological age of plants on the uptake and assimilation of radioactive phosphorus.

To study the interrelationship of the effect of soil temperature on the availability of soil phosphorus, the uptake and assimilation of phosphorus by vegetable crops at various growth stages, and proper phosphorus management of Oregon soils.

This study of the differential utilization of phosphorus by plants as influenced by soil temperature and the morphological age of plants at the time phosphorus is applied has resulted in a more sound basis on which to predict the phosphorus requirements of plants.

In Oregon alone on one commercial crop (10,000 acres of pole beans) more than $100,000 of phosphorus fertilizer is applied each year. When applied at the proper stage of growth and when soil temperatures are low, the increase in yield from phosphorus fertilizer is conservatively estimated at one ton per acre. At the average price of $120 per ton, this increase has the 10,000-acre valuation of $1,200,000 annually. If this research has contributed 25 percent to the efficiency of use of phosphorus fertilizer for one crop in one state, the dollar value in gain to the growers concerned is $300,000.

51. Detoxification mechanisms in insects.

To study the biochemical processes by which insects detoxify or metabolize insecticidal compounds.

This is a basic study to determine:

(a) If insects use classical methods to detoxify various compounds.
(b) The mechanisms involved in the development of resistance to insecticides.

No monetary estimate can be made of the value of this project but potentially it may prove of real value.
52. a. Biochemical effects of phosphorus and nitrogen deficiency in algae and higher plants.

b. Investigations of pathways in plant metabolism: several phases of plant metabolism which have been investigated in this laboratory during the past year have disclosed significant interrelationships. Of particular interest are those observations which have a bearing upon animal metabolism. A number of the lines of research followed under this contract during the past three years have resulted in discoveries of widespread interest which have elicited our efforts in new directions.

Neutron Activation Chromatographic Analysis has proved invaluable in the quantitative and qualitative estimation of the phosphorylated compounds derived from the phospholipids of plants and animals. The results have been better than anticipated and will prove particularly useful in the analysis of phosphorus-containing compounds from larger animals which cannot readily be labeled with $^{32}$P.

Radiochemical Identification of Diglycerophosphate and the Phosphatidyl Glycerols was reported in 1957. The new phospholipid has now been observed in all animal tissues investigated. It undoubtedly plays an important role in metabolism. An inverse interrelationship between the concentration of diglycerophosphate and phosphatidyl glycerol has been observed in plants. During illumination the concentration of the phospholipid increases at the expense of that of diglycerophosphate. Investigation of the Biosynthesis of the Glycerolphosphatides in Chlorella has led to our observation of the importance of the new group of glycolipids. The concentration of these galactose-containing lipids far exceeds those of the phosphatides.

Phosphorus Deficiency in Plants markedly reduces the rate of photosynthesis. The effect of light upon the respiratory pathways under these conditions is a decided diminution of tricarboxylic acid cycle function. The study of the Respiratory Metabolism of Glycolate and Acetate in Plants has been continued. It appears that glycolic acid oxidation plays a primary role in light respiration of plants.
Radiochemical Identification of the Sulfolipid of Plants has been completed during the past year. This new lipid, β-galactoside-6-sulfate of a monoglyceride, occurs in high concentrations in all green plants and has not yet been observed in animal or nonphotosynthetic tissues. The photosynthetic relationships of the sulfolipid and the galactolipids was disclosed in a study of their biosynthesis from Cl4O2.

Acid hydrolysis rates of several of the glycerophosphoryl esters derived from the glycerolphosphatides have been determined. The structure of phosphatidylinositol has been investigated by proton magnetic resonance spectrometry.

53. a. Metabolism of bovine semen.
   b. Flavor and color defects in milk and milk products.

54. a. Soil structure.
   b. Physiological and nutritional investigations with corn and other crops.
   c. Fertilizer experiments.

Cannot estimate economic benefits to agriculture. Basic research.

55. Work in bacteriology, and botany utilize radioisotopes as well as a cesium source radiation field.

XVII. 56. Study H-1 Nutrient Element Requirements. These studies have been concerned primarily with the nutrition of the tomato plant during its various stages of development. In "direct seeded" tomatoes it has always been recommended that a complete fertilizer (NPK) be banded near the seeds. Our studies indicate that only phosphorus should be used. There has been no response to nitrogen or potassium; in fact, at the higher levels these nutrients hindered the growth of the young seedling.

57. Study H-2 Uptake and Loss of Water from the None-Root Parts of Plants. Attempts are being made to use the absorption of weak beta particles as they pass through leaves to measure the leaf moisture content and then to be correlated
with internal moisture stress. Such a technique will allow
one to determinate the critical time for application of
irrigation. It is expected that this instrument and tech-
nique will be placed on a practical basis this summer.

58. Study H-3 Movement of Nutrients in Plants. This study is
two-phased. First, it has been shown that at least two
weeks are required for fertilizers banded on a single side
of plant or even two sides, to be distributed in the plant
to equilibrium. This is due to the anatomical arrangement
of the conducting tissue and its relations to the root sys-
tem. The over-all result is a knowledge of how better to
place fertilizer applications; thus, a more economical uti-
лизation of applied fertilizer. Second, the effect of
growth on redistribution of applied elements. Certain ele-
ments are easily retranslocated and thus fertilizing can
be made in one application. Other elements are not retrans-
located and the plant must have a continual supply. Thus,
under certain conditions more than one application is desir-
able and profitable.

59. Study H-4 Leaf and Tissue Analysis. Minimum and maximum
foliar nutrient element contents have been obtained for
various apple varieties and dwarfing root stock combinations.
These data allow us to make more accurate fertilizer recom-
mandations.

60. Study H-6 Breeding to Improve Forms. In crossing plants
in the production of hybrids, it is necessary to grow the
plants to a given stage of development to ascertain whether
one actually has the cross. This, in many cases, is cir-
cumvented by use of seedling characteristics such as leaf
type, etc. We have developed a technique where by label-
ing the parent pollen we can induce the hybrid seed to
possess radioactivity and thus, by use of a Geiger counter,
determine if the seed is or will give us the desired hybrid.

61. Study H-8 Mechanism of Action of Pesticides. The accuracy
and sensitivity of measurements of minute quantities of
radioactivity allows one to determine residues of labeled
pesticides (herbicides, insecticides, fungicides, etc.) in
edible food products. We have used this technique in assist-
ing commercial concerns in furnishing the Federal Drug
Administration adequate data to determine the tolerances
of several of these important pesticides.
62. Labeled herbicides and fungicides have been the means for proving no residue following application of the chemical, thus allowing registration for use by the public.

63. Labeled charcoal fed to livestock shows that charcoal is of little benefit in the feed and the farmer cannot afford to pay for its inclusion.

XVIII. 64. Study of absorption, metabolism, detoxication, and excretion of nematocides and insecticides (primarily systemic). P\textsuperscript{32} utilized in studies of absorption through gut wall under influence of systemic and nonsystemic insecticides. P\textsuperscript{32} labeled insecticides used to study metabolism and detoxication systems—utilize column chromatography and infrared spectrophotometry for identification of metabolic products. Utilize rabbits, rats, bees, and cockroaches for \textit{in vivo} studies. Utilize isolated rat and rabbit liver slices, and insect tissue for \textit{in vitro} studies.

65. Study of dispersal of infective nematode larvae on pasture. Study methods of tagging nematodes with P\textsuperscript{32} or C\textsubscript{60} for these studies.

It is believed that if cattle grub could be controlled 100 percent, cattle value per head would be increased approximately $4.00. Control of sheep parasites would increase value per head approximately $2.00.

66. A project has been completed to determine the effect of reducing water solubility of phosphate materials in fertilizer. P\textsuperscript{32} was used as a tracer. It is very difficult to place an economic evaluation on the determinations made in this study.

XIX. 67. Measurement of moisture content of soils under various conditions using a neutron source. No estimate of economic value; study is in initial phase. A more rapid method for measuring soil water, thereby increases the scope of research work that can be done in this area.

68. Uptake and availability of several phosphate fertilizers from various South Dakota soils under dryland and irrigation management. No estimate of economic benefits at this time. Use of radiophosphorus led to discovery that fertilizer phosphorus utilization was increased up to 100 percent by joint application with a nitrogen carrier.
69. Production of mutations in corn, barley, and sorghums (principally) using $^{60}$Co-rays and X-rays; tests of theories of gene action; information to be used in breeding work. The study has been fundamental and no estimate is made of their economic benefits for agriculture at this time.

70. Production of mutants which can be used in breeding programs for increasing disease resistance (root and stem rots in corn; wilt in flax) in certain plants, using thermal neutrons. It has been estimated that the control of one of the three or four diseases affecting corn increases yield by 25 percent—eight to nine bushels of corn per acre.

71. A study of sulfur and selenium metabolism in wheat seedlings. *Astragalus racemosus* plants, and yeast using tracers. Identity of selenium-containing intermediates and of anion interrelationships on uptake and accumulation are goals of the study. These fundamental experiments have not been assessed for economic benefit.

XX. 72. Cotton—irradiation of cotton seed to produce chromosome breakage and mutation for use in genetic studies.

Small grains—same as for cotton.

Dallis grass—production of genetic changes in Apomictic and other native grasses: grasses with emphasis on desirable agronomic characteristics.

73. Rice—irradiation of seed to produce chromosome breakage and mutations. Cobalt 60 has been the most commonly used radioactive isotope for most crop seeds.

74. Cotton, rice, small grains, and Dallis grass have aid in identifying and producing heritable changes which aids in the study of genetics. These basic studies will ultimately contribute to better quality, insect and disease resistance which will be of definite economic benefit to producers, processors, and the consumers.

Work with cotton and rice has already aided the plant breeders by providing sources of variable germ plasm.
75. "Defoliation and Desiccation of Cotton under Texas Conditions." C14, p32, and S35, labeled chemicals have been used to follow the absorption, movement, and metabolism in cotton, including chemical residues in fiber and seed. Specifically labeled pentachlorophenol, cyanamid, amino triazole, and thiophosphate studies have been completed. These studies have aided in the development of new cotton preharvest chemicals and in conjunction with mechanical harvesting have reduced harvesting costs about 50 percent. This involves about an eight million dollar business in this state.

76. "The Influence of Physiological Factors Involved in the Reaction of Cotton to Insect Attack and Insecticide Application." p32 labeled systemic insecticides have largely been employed to follow their absorption, movement, metabolism and residue in cotton. The results have aided in the perfection of more effective insecticides and means of application. These have increased cotton yields and reduced cost of production.

77. S-1195, "Radiochemical Studies with Ethylene in Plant Metabolism." This study involves the absorption and metabolism of ethylene by plants including cotton, grain, sorghum, and fruits. The objectives are fundamental to gain a better understanding of how ethylene affects abscission, fruit coloring, ripening, etc. It is difficult to estimate the economics of agriculture at this stage.

78. "Selected Air Pollutants Affecting Plants and Health." This study has been initiated this year to determine how industrial gases and noxious chemicals affect crop and ornamental plants. The economic benefits are long range and difficult to estimate at this stage. Effects upon yield, quality, etc., will be studied under controlled conditions in plants such as cotton, sorghums, peanuts, tomatoes, and other selected species.

79. Other studies involving graduate student problems and not listed under station projects have been conducted with labeled herbicides, nutrients, and fungicides. Cotton, cereals, mesquite, and weeds, and fungi, including penicillinium have been used in the problems.
80. Interrelation of essential fatty acid, phospholipide, and cholesterol metabolism: the possible role of the relationship in the genesis of atherosclerosis. No dollar and cents economic benefits can possibly be estimated as a result of this work, however, since this work may indicate a health relation between the ingestion of fats and the kind of fats ingested on a long-term basis, it could affect the consumption of fatty foods, or, at least, the ratio in the kinds of fatty food produced by agriculture.

81. The biosynthesis of polyunsaturated fatty acids by the laying hen. This work also involves no direct foreseeable influence on the economic benefits to agriculture. Indirectly, however, the relationship between the kinds of fat ingested by laying hens and the nature of the fat in the eggs could affect the consumption of eggs because of an inference on the effect of their fat on health and possibly on the storage of the eggs.

82. Variation in deposition and catabolism of fatty acids. There is no foreseeable agricultural economic benefit that would result from this study.

83. Chemistry and biochemical behavior of lipides. There are no foreseeable direct agricultural economic benefits which would result from this study.

84. Cotton boll weevil damage runs from $10 to $20 per acre: results of research on the boll weevil may furnish information which can be used for controlling many other insects and reduce the costs of control accordingly.

85. Biosynthesis of indoleacetic acid: A study of the synthesis of this growth stimulator in oat coleoptiles and watermelon slices is aimed at determining the enzymatic reactions involved in this process and the intermediates produced. By a knowledge of the reactions and intermediates involved it would be possible to better control plant growth in general, thereby improving quality and per acre yield, and decreasing the environmental effects on crop production. In correlation with this work, determinations are being made on the distribution of IAA and its metabolic intermediates in the pine tree with similar economic objectives in mind.
86. Sulfur metabolism in plants: The pathway of enzymatic reactions involved in the incorporation of inorganic sulfur compounds into organic sulfur constituents of the plant has not been elucidated. Working with Neurospora mutants and pea roots experimental data is being collected to determine the order of reactions involved in the synthesis of sulfur-containing amino acids. Conclusions from such a study would be of economic benefit by supplying information concerning plant nutrition which could be utilized for better crop development.

87. Insect resistance to chlorinated hydrocarbon insecticides: The effect of toxaphene and other chlorinated hydrocarbons on the oxidative metabolism of the boll weevil and Drosophila has been studied with the objective of determining a possible respiratory mode of action for those chlorinated insecticides which effect an increase in insect respiration. This study was initiated to determine the mode of action of these insecticides on a cellular level with the hope that such information could serve as a basis for further research on determining the biochemical factors imposed by the genetic differences responsible for insect resistance. By determining the enzymatic reactions which are affected by these insecticides and how these particular enzymes differ in the susceptible and resistant insect, it would be possible to "build" an insecticide which would be toxic to the resistant insect by virtue of its ability to nullify the resistant mechanism. A culmination of such a study could greatly benefit any commercial venture to which insects are a menace.

88. Translocation of hexachloroacetone and trichloroacetic acid in the cotton plant: The possible damage which could result from the root uptake and translocation of HCA and TCA, weed killers, in the cotton plant was of concern to the farmer. A study was made to determine if appreciable amounts of these weed killers were absorbed by the plant. Results of this study show that a negligible amount of either HCA or TCA is taken up by the cotton plant. It could be concluded that these weed killers would be safe for application near the roots of cotton.

XXI. 89. Thousands of acres of valuable crop land, positionally and climatically capable of producing high-cash horticultural crops, are growing low-value crops because of micro-nutrient
deficiency problems. Lime-induced chlorosis—appearing as an iron deficiency—occurs on calcareous soils containing ample iron. A better understanding of the soil-plant relationships causing such a physiological deficiency should allow maximum use of our high-value land. The relationships found will expand our basic knowledge of soil-plant-nutrient interactions, thereby allowing greater utilization not only of our land but of the large quantities of amendments we add yearly, such as fertilizers or sprays.

90. Federal and State Experiment Stations as well as private breeders of beef cattle are putting much effort into improving cattle for efficiency of gain. There is need for increasing the accuracy of efficiency measures. For refined measures information is needed on composition of the gains. Tritium has proven in our tests to be more accurate than antipyrene which has frequently been used. The technique of using tritium for this purpose is too technical for wide commercial use. It will be valuable to the researcher who is concerned with developing accurate procedures for measuring efficiency in cattle. More simplified methods may be developed later that can be applied commercially.

XXII. 91. The research in which we have used radio-active tracers has been of a basic nature. Thus it is difficult to indicate the economic benefits to agriculture which have resulted. As you will note by our report the amount of work which has been undertaken at this University has been relatively small. It would be difficult for us to use additional money as indicated in column 3 of the questionnaire unless we could add more permanent people to our staff. Our research personnel who are currently engaged in radio-tracer work is limited and these scientists could not undertake a large amount of additional work. Therefore, I have not indicated that we would be able to undertake additional research if proper support was forthcoming. To us proper support would be of such a nature as to allow us to add personnel. We would be interested in expanding in the fields of animal nutrition, physiology as well as in soil and water research.

XXIII. 92. A study of methods, equipment, operating practices and costs in measuring bulk milk.
Isotopes used in studying soil removal from milk handling surfaces. Attempts are being made to find better, cheaper, and more efficient methods for cleaning dairy equipment. Cannot estimate financial benefits as yet.

93. Movement of insecticides in soils. First phase: project completed (P$^{32}$). Second phase: fumigant action of soil insecticides, using Lindane, DDT ($C^{14}$), etc. Contributes basic information toward the understanding of the fate of insecticides in soils.

94. The type of work being done with radioisotopes in this department is not easily evaluated in terms of per-acre or per-unit-of-product. However, we feel that three of the projects which have been undertaken by the department have provided information which has enabled us to improve our fertilizer recommendations.

a. A study of the depth and extent of subsoil feeding by crops such as corn and alfalfa has given us a basis for evaluating the importance of subsoil nutrients. This information is helping us to improve our fertilizer recommendations.

b. Studies on proper placement of starter fertilizers for corn have contributed to the change from split boot planters to band applicator. This change has increased the efficiency of the row fertilizers by as much as 10 percent.

c. Studies on the efficiency of various forms of phosphate fertilizer have the potential of saving the farmers of the state from $1.00 to $2.00 per ton on fertilizer materials. Last year approximately 440,000 tons of fertilizer were sold in the state.

95. These projects do not deal directly with farm animals, but rather with basic biochemistry and physiology of animals. Specifically,

   (a) The biosynthesis of cholesterol by normal liver and normal skin.
   (b) The biosynthesis of sterols in skin damaged by carcinogenic agents or by diets deficient in certain vitamins.
(c) The effect of glycine in diminishing protein losses in the urine.

Any practical benefits are more likely to be medical rather than economic.

96. Our studies have been basically directed toward examination of the enzymatic mechanism of biological N\textsubscript{2} fixation. We work with leguminous plants and the nitrogen fixing bacteria. I couldn't begin to estimate if such investigations contributed to commercial agriculture but they certainly contribute to scientific agriculture. I have the feeling that their chief contribution is the training they afford to young graduate students who subsequently make important contributions to society including commercial agriculture.

97. The mechanism of action of the growth inhibitor, maleic hydrazide.

The effort was to determine the mechanism by which maleic hydrazide is able to prolong dormancy in woody, perennial plants such as trees, fruits and ornamentals. The ultimate practicality of such use of chemicals is to prevent spring frost injury. C\textsuperscript{14} was used.

This is a problem the world over wherever there is frost. It would be impossible to estimate the extent to which this study has contributed to the problem.

98. The behavior of the diphenylurea herbicide, monuron, in the upper one inch of soil.

The movement of the chemical into seed, seedling, and established plant was followed. The integrity of the compound was studied following its entry into living tissue. (C\textsuperscript{14} was used.)

There is no immediate commercial advantage in this finding.

99. The competition of plants below the soil surface.

The measure of interference between weed and crop roots is being studied. P\textsuperscript{32} is used to "diagram" the active, feeding roots of typical weeds and crops. The plants are then grown together in model systems to study competition for
space and for P\textsuperscript{32}. The crops studied are vegetable at present.

There are no immediate commercial advantages of this study.

100. Radioisotopes have been used to help clarify the movement of spores from the oak wilt fungus through root grafts from an infected oak tree into a nearby healthy tree. Thus these isotopes have been an important tool in providing a critical and fundamental basis for the control measures now being used against oak wilt. This disease has been dangerously active in 18 midwestern and eastern states where oaks are the most important trees for many uses. The value of these oak trees greatly exceeds that of the chestnuts that were killed long ago by chestnut blight. The economic value of the oaks is tremendous.


102. Biological activity of insecticidal derivatives.

These studies show how phosphorus insecticides work, and form a basis for the preparation of new insecticides of predictable properties. They also are designed to discover the reasons for synergism in mammals and for resistance in insects, so that these phenomena can be either avoided or countered.

103. Chemical nature and mechanism of loss of insecticide residues on or in food, feed and forage crops.

This work describes the nature and quantity of potentially hazardous residues in crops and stock following the use of phosphorus insecticides e.g., in tomatoes, corn, cotton, peas, potatoes; cow and goat.

104. The effect of diet on the absorption and utilization of Ca and P: Although these studies are conducted on rats, their applicability is of a more general nature. They are of benefit in evaluating the needs of these mineral elements under conditions of widely varying diets frequently encountered in agriculture.
105. The mechanism of action of Vitamin D.

An understanding of the influence of Vitamin D on metabolic processes may be of practical value in its therapeutic use and limitations. Of particular importance to the fields of medicine and agriculture are the sites of concentration and action of the vitamin.

106. Photosynthesis and organic acid metabolism in spinach and tobacco plants. No evident economic value yet.

107. Isotopes in the study of rumen physiology of cattle. Impact on nitrate poisoning of cattle in central Wisconsin might eventually be $25,000 a year.

108. A very minor experiment was carried out in the greenhouse in which radioactive calcium added to the normal nutrient was used to trace calcium movement in cabbage plants grown to maturity. The results showed, in confirmation of chemical analyses, that calcium moves very slowly into the margins of internal head leaves where the disease known as tip burn occurs.

XXIV. 109. Selenium poisoning: The use of radioactive selenium in studies dealing with the effect of selenium on growth, reproduction, and the mechanism of intoxication will be immense value to prevent or counteract losses in livestock due to selenosis. This loss at the present time may be estimated to be above $200,000 per year. The losses due to inhibition in growth and reproduction are difficult to evaluate, but it appears that small amounts of selenium, which produce no obvious toxic symptoms, nevertheless decrease growth rate and fertility of animals by as much as one-third. Reduced weight gain and loss of fertility, although difficult to estimate, probably cause an economic loss estimated at $200,000 to $300,000 per year.

110. Mineral metabolism studies: The requirements of mineral elements by range animals and the functions of these elements in range animal metabolism appear to vary with ecological and environmental conditions. Artificial mineral supplementation of diets is complicated by the interaction of supplemented minerals and those available from the native forage. Studies with radioactive labeled mineral elements should lead to improved and more selective formulation of mineral supplements for specific grazing areas.
and species of stock. The value of wise supplementation and the prevention of supplementation which is actually harmful under some range conditions should mean savings of several hundreds of thousands of dollars to ranchers and stockmen.

111. Body composition in sheep by isotopic dilution using tritiated water. Body composition is an accurate reflection of nutrient usage and availability. As a research tool, the accurate determination of body composition would be most valuable in nutritional and genetic studies. It is estimated that such would be worth $100,000 per year to research institutes throughout the country.
In the second phase of the survey, about 70 questionnaires were sent to other users of radioisotopes in agricultural research. Information on holders of licenses for use of radioisotopes in research in the life sciences was obtained from the Atomic Energy Commission files. Information on isotopes licensed and proposed isotope uses was subsequently screened to eliminate all but those licensees doing work that could be classed as distinctly applicable to the agricultural field. Licensees engaged in work of an extremely basic nature, even though at some future date it might have ramifications in the agricultural field, were eliminated.

The remaining licensees, forty-three in number, were sent questionnaires and asked to report on their present and anticipated future programs utilizing radioisotopes in agricultural research. Nonrespondents were contacted by telephone, so that answers were obtained from all these licensees except three who still had failed to return their questionnaires at the time this report was written.

Questionnaires were also sent to 22 holders of broad and comprehensive licenses who were not included in the other list, but who, it was believed, might be engaged in agricultural research. The nonrespondents were not contacted again since responses showed that most of this group were in fact not engaged in agricultural research. Only two positive responses from this group were received, both from universities.

A sample of the questionnaire can be found on the following pages.
Stanford Research Institute is conducting research for the Atomic Energy Commission directed toward estimating the advantages and benefits obtained from all research in agriculture involving radioisotopes.

Atomic Energy Commission records indicate that you may be using radioisotopes in agricultural research and your cooperation in completing the enclosed questionnaire will be of great value in appraising the potential benefits of isotopes. We believe that a complete response to this request will provide information of importance and value, both to the AEC and to organizations now conducting programs using radioisotopes. The results of our research will become available in published form later this year.

We realize that estimating possible future increases in the efficiency of certain farm supply items is quite conjectural. However, we hope that you will make some educated guesses of such increases and the extent to which these might affect farm yields.

Stanford Research Institute has had considerable experience in handling and publishing confidential information. Specific data from any one organization will not be revealed.

We have provided a postpaid and addressed envelope for your convenience, and would greatly appreciate hearing from you. We hope you will return this questionnaire even though you are not engaged in agricultural science research. If you are unable to complete the questionnaire, we hope you will be able to send us any analyses or reports you might have concerning your agricultural research activities.

Thank you for your very kind consideration and assistance.

Sincerely,

Richard R. Tarrice, Head
Nuclear Economics Research

RRT: jm
Enclosures: (2)
Are you engaged in research involving radioisotopes in agricultural sciences? Yes ___, No ___. If yes, state the specific fields of animal, plant, or soil sciences, or technology in which you conduct research involving radioisotopes (such as fertilizer uptake, insect physiology, dosimeter instrumentation).

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<th>Fields of Research</th>
<th>Isotopes Used</th>
<th>Number of Projects Underway in FY 1958-59</th>
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Magnitude of all research in agricultural sciences involving radioisotopes under in fiscal year 1958-59 in _______ dollars or in _______ man-years.

Percent of total agricultural research program _______ percent.

How much do you expect this research effort to increase in the next five years: estimate percent increase over the 1958-59 level.

_______ percent Radioisotopes

_______ percent All Agricultural Research

What new or better farm supply items, such as certain types of fertilizers, pesticides, feeds and seeds, might be developed in the near future through research involving radioisotopes, and how would these items affect money or product yield?

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<th>Amount</th>
<th>Change (+ or -)</th>
<th>Product Yields (specify units)</th>
<th>Dollar Net Returns (specify units)</th>
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<tr>
<td>grains</td>
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SURVEY OF TWELVE AGRICULTURAL JOURNALS

An analysis of twelve agricultural journals which are listed in the table on the following page, was made for the period from 1952 to 1958. The ratio of the number of articles on the use of radioisotopes in agricultural research to the total number of articles was determined.

The number of articles on radioisotopes was fairly steady from 1952 to 1957, but it almost doubled in 1958. Their percent of all articles ranged from a low of 2.46 percent in 1957 to 4.60 percent in 1958. The number of all articles presented in these journals has increased by one-third during the period.
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1/ Figures in parentheses are in part estimated.

Source: Stanford Research Institute.
REGIONAL OFFICES AND LABORATORIES

SOUTHERN CALIFORNIA LABORATORIES
820 Mission Street
South Pasadena, California

SOUTHWEST OFFICE
3424 North Central Avenue
Phoenix, Arizona

PACIFIC NORTHWEST OFFICE
421 S. W. 6th Avenue
Portland, Oregon

WASHINGTON OFFICE
711 14th Street N. W.
Washington, D. C.

EUROPEAN OFFICE
Pelikanstrasse 37
Zurich, Switzerland

HAWAII OFFICE
195 South King Street
Honolulu, T. H.

NEW YORK OFFICE
60 East 42nd Street
New York 17, New York