Atomic Energy in Agriculture

Work already accomplished with radioisotopes points to exciting possibilities for the future

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In framing the Atomic Energy Act of 1946, Congress recognized that continued U. S. leadership in atomic energy depends upon a broadly conceived and forward looking program of fundamental research guided by the initiative and insight of scientists themselves. To this end funds have been available for nearly a decade to qualified investigators to engage in a broad program of fundamental research involving many fields of science, including agriculture and related areas. To provide tools for such research AEC's Division of Radio-Isotopes was created in Oak Ridge, Tenn., to supply a great variety of radioisotopes and radiation sources at prices easily within reach of the average investigator. A variety of radiation detection instrumentation that will meet practically any research application using radio isotopes has also been commercially developed. In addition scientists themselves have developed to a fine art such new research tools as radio-autography and paper chromatography, both of which are invaluable aids to the art of radiochemistry.

It should be recognized that use of radioactive materials in the field of agriculture is not a new development—in fact it dates back some 50 years. However, the major accomplishments in radiobiology and radiochemistry have been made in this decade. The main objectives of the Division of Biology and Medicine of the Atomic Energy Commission have been the protection of human life and health in connection with AEC activities and for the extension of fundamental knowledge of the effects of radiation on living things of all kinds. The studies on the mechanisms of radiation injury to plant cells lead inevitably to fundamental questions of plant nutrition and the science of the inheritance of plant characteristics, from one generation to another.

With the impetus thus given to agricultural research an extensive and fruitful program has resulted. The work accomplished can be divided into two major fields, namely direct use of ionizing radiation, and the employment of emitting materials to detect their subsequent action or movements. The latter field employs radioisotopes, better known as "tracers."

Radiation Effects and Applications in Agriculture

The direct use of ionizing radiation in the field of agriculture has been employed to preserve perishable materials and to change plant characteristics. Since radiation sterilization has been widely reported no attempt will be made to repeat such information in this article. On the other hand, the possibility of changing plant characteristics by irradiation to increase yield, produce disease resistance, and in general alter plant structure to a more desirable form has not been widely reported and has interesting possibilities.

Basically, large doses of irradiation produce mutations: that is, changes which will be subsequently inherited from generation to generation. Ionizing radiations dissipate their energies by colliding with the molecules of substances being irradiated. These collisions result in either the excitation or the ejection of electrons in the affected molecules. As a result of electron excitation and ejection, chemical properties of the irradiated substrate are frequently altered. It is theorized that gene mutations result from the altered chemical properties of genes, due to either excitation or ejection. Chromosomal aberrations would then result from a greater number of ionizations or electron ejections, occurring throughout the diameter of the chromosome, thus disrupting the chemical bonds which normally maintain the chromosome as a single unit.

It is known that fractured ends of chromosomes have an affinity for one another. A chromosome fragment may rejoin the portion of chromosome from which it originally detached, a process called restitution; or fragments unconnected before irradiation may become attached, a process called translocation. While plants so changed are often economically unfit and will not survive, a desirable mutant is occasionally produced.

In work at Brookhaven National Laboratory irradiation techniques have been used to develop several desirable plant mutants that have not only given increased crop yield but that have acquired, in some cases, specific disease resistance. Shorter corn plants have been developed, yielding a greater ratio of grain per stalk. Rust-resistant oats have also been developed by neutron irradiation. At the North Carolina State College of Agriculture a variety of peanuts has been produced with 30% higher yield per acre, sizes and shapes better adapted to mechanical harvesting, and resistance to the common leaf spot disease.

Argonne National Laboratory scientist examines canna leaves which are to be used for synthesizing radioactive sugar

The greater number of mutations producible by radiation has been expressed as follows. In normal corn one would need to examine over 26,000 kernels to find 12 colorless, 5 sugary, 8 red, and 3 shrunken mutant kernels. However, the right amount of radiation at the proper time will allow one to find 32 colorless, 35 sugary, 26 red, and 17 shrunken kernel mutations in 1600 kernels. In other words, the task of finding mutants has been made easier by a hundredfold as a result of radiation treatment.

Radiation mutants are not always deleterious as previously believed but can in fact produce a superior plant or animal, as far as economic use by man is concerned. With the greater degree of selectivity now possible, many new, desirable plant varieties can be anticipated.

Radioisotopes in Agriculture

In contrast to the direct employment of radiation for sterilization or increase in plant genetic mutation frequency which in both cases requires large, humanly lethal, amounts of radiation, the field of radio-isotope application can be accomplished with small, relatively nonhazardous amounts of radioactivity. This has been made possible through the development of techniques and detection equipment capable of measuring increments of radiation down to their vanishing point. Indeed, it has been stated that one can now detect individual molecules.

Isotopes that could easily be followed by radioactivity were hard to come by before 1940. Since then, nuclear reactors have produced large quantities of radioisotopes of interest to agriculture. They can be used for studying the nutritional requirements of animals and plants action of agricultural chemical products, tenacity of spray residues, insect migration, toxicology of chemicals, and numerous other problems. Briefly, use of a radioisotope involves first obtaining the radioactive element as part of a simple molecule, treating this molecule with other compounds to form the desired tagged material, introducing this material into a plant or animal, tracing its course with counting equipment, and finally determining amounts moved or incorporated into other products by a combination of counting and chemical techniques. In some studies the simple radioactive material may be used directly as for instance the use of heavy water to measure water uptake. Other isotopes are supplied in convenient forms such as phosphorus-32 in the form of phosphoric acid which needs only be diluted to study phosphorus uptake in plants. As one would expect, radioactive isotopes of the different elements differ widely in their nuclear properties. The type and energy of radiation is extremely varied as well as its persistence which is

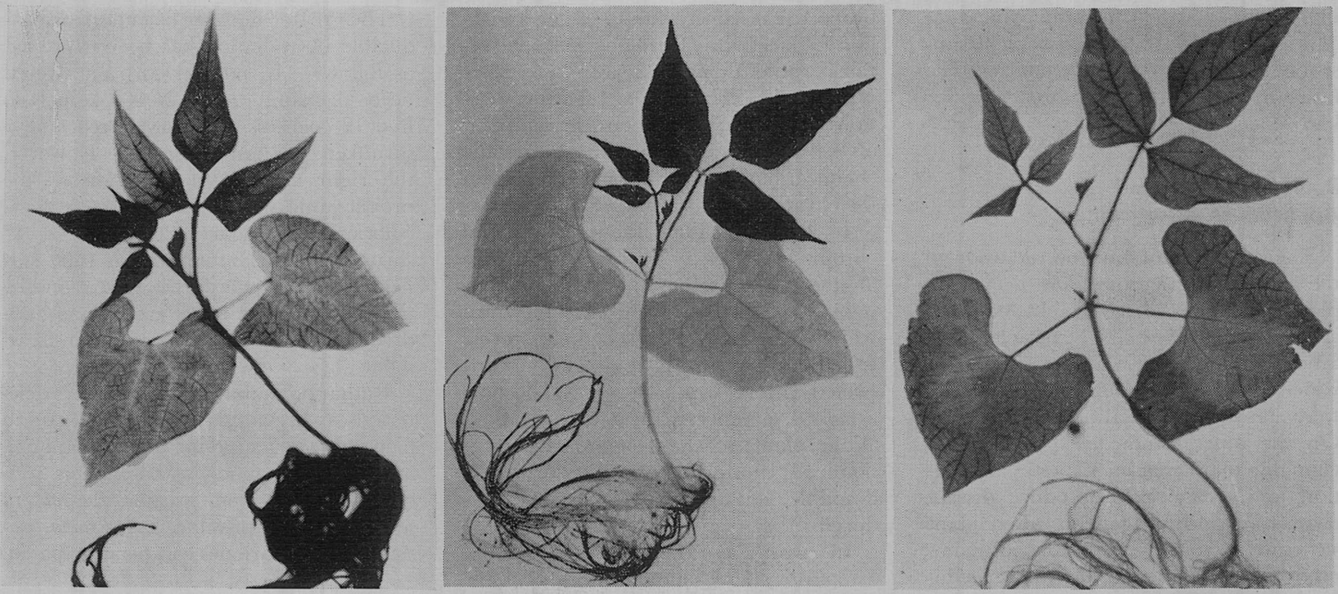

Figure 1. Radioautographs A, B, and C demonstrate movement of phosphorus-32, sulfur-35, and calcium-45, respectively, into bean plants

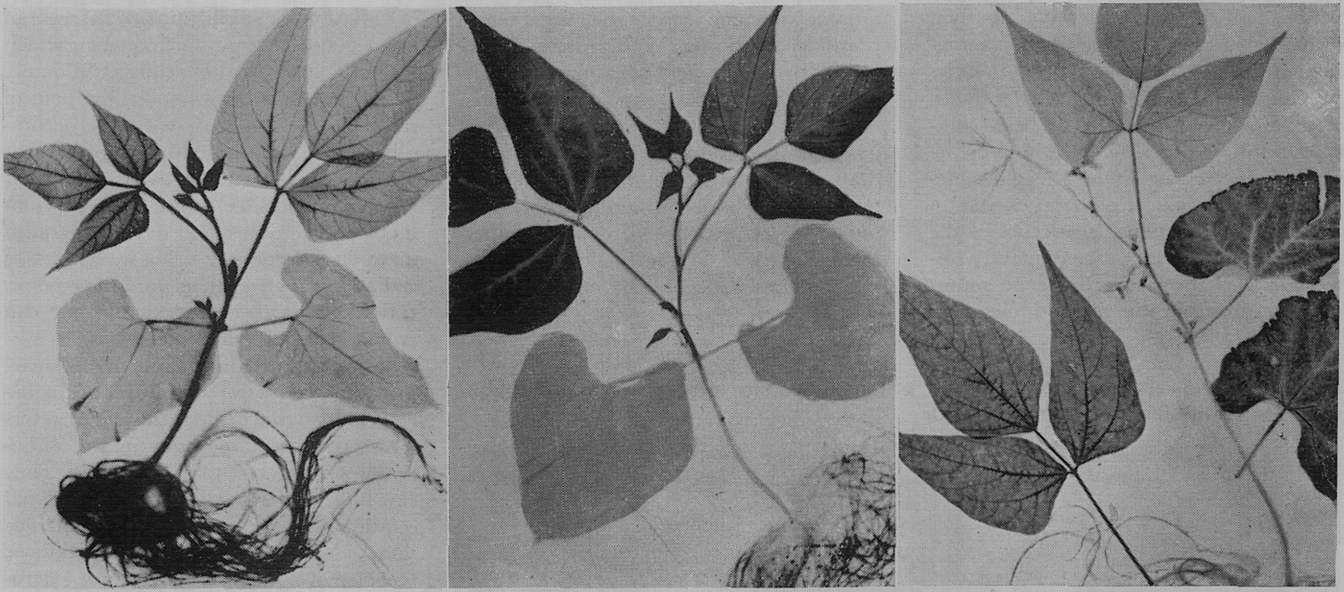

Figure 2. Radioautographs A, B, and C demonstrate movement of phosphorus-32, sulfur-35, and calcium-45, respectively, within the bean plant. Plants were removed from radioactive nutrient media four days before harvest

commonly termed "half-life." In the case of nitrogen *all radioactive isotopes* have a half-life in seconds and obviously cannot be employed for uptake or other studies requiring a much longer interval of time for completion.

The type and energy of emitted radiation *from any one* isotope differ widely. As certain radioisotopes undergo spontaneous disintegration, one or more types of radiation are emitted, such as positively charged alpha particles, negatively charged beta particles, and gamma photons. The gamma photons or rays behave like x-rays but are produced instead by disturbances within the nuclei rather than in the electrons that circle the nuclei of atoms. Gamma rays and x-rays are waves of electromagnetic energy having very short wave lengths, the gamma rays being even shorter than x-rays with greater penetrating power. Both types, however, have considerably *greater penetrating ability than the beta* particle. Beta and gamma emitters can be measured by the popular type of Geiger-Müller counter. However, some beta emitters may have very low energy values, tritium for example, requiring specialized counting equipment.

On the other hand an alpha emitter ejects a doubly charged helium ion with a velocity of about 2×10^9 cm. per second with a very high specific ionization of about 25,000 ion pairs per centimeter. So much energy is dissipated in this ionization that the particle can penetrate through only 1 to 11 centimeters of air or 0.001 inch of aluminum. Therefore an alpha-emitting isotope must be measured in the chamber itself of what is known as a proportional counter. In any research, therefore, using a specific isotope, the activity necessary to give the desired end detection result must be *carefully calculated*, and the type of radioactivity will govern selection of required counting equipment. In preparing specimens for radioautographic illustration an extremely accurate calculation of activity and exposure time is required to produce a definitive negative.

An illustration of both the usefulness of radioautographic techniques and the contribution of radioisotopes to a better understanding of fundamental agricultural problems is the work by Orlin Biddulph of Washington State College. This work, described below, has contributed greatly to an understanding of the movement and deposition of required elements in plants. Plants were grown for the last four days in three nutrient solutions containing 1.32 microcurie of phosphorus-32 per liter, 8.20 microcuries of sulfur-35 per liter, and 2.20 microcuries of calcium-45 per liter. The plants were then harvested and exposed to Eastman Kodak, no-screen x-ray film for 14, 90, and 60 days respectively. Observation of the radioautographs indicates that the element in each case was taken up by the plant and moved to all tissues. In Figure 1A, it is apparent that new growing tissue and root has a larger concentration of phosphorus than the older leaves. Figure 1B shows a somewhat more sulfur in new growing tissue than in stem and older leaves and little root concentration. Figure 1C clearly demonstrates that calcium is very uniformly deposited in all plant tissue.

To demonstrate the mobility of elements, once acquired by various tissues within a plant, Dr. Biddulph added radioactive material to the nutrient media for four days and then grew the plant the last four days in normal nutrient media. The plant roots were carefully washed to remove all traces of radioactive material before being placed in the normal nutrient media. In this experiment the new growing tissue could only obtain the required element in radioactive form from other older tissue. Figure 2A demonstrates quite clearly the movement of phosphorus from older leaves to the new growing tissue where it has concentrated to approximately the same level as shown in Figure 1A. Figure 1B also demonstrates that sulphur is mobile but less so than phosphorus. In Figure

John W. Mitchell, plant pathologist at USDA's Plant Industry Station, applies a small amount (25 micrograms) of a radioactively tagged plant growth regulator to the tip of a bean leaf

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2C it is evident that calcium, once absorbed into plant tissue, is deposited and is not freely mobile. The amounts of radioactive material introduced into the plant nutrient media and the time of exposure to film of radioautographs in Figure 2 were identical with those listed for Figure 1.

Another method of determining element mobility in a plant is the injection of radioactive material in proper solution into a leaflet through a "leaf flap" which might be described as a nearly parallel incision at the upper surface of the leaf. This technique is performed with an extremely small quantity of radioactive material and easily available x-ray film. In one such experiment comparing the mobility of phosphorus, calcium, and iron, only phosphorus showed significant mobility. No calcium has moved and only a trace of iron.

In a practical sense it is apparent that calcium must always be available to a plant root in order that new plant growth will have the needed amounts. On the other hand it is evident that a plant can be "slugged" with phosphorus either by spraying the foliage or the usual soil-root application method and the plant will essentially store the phosphorus, giving it up as needed from older leaves and the root system. From similar studies the element iron is also found to be stored in, or adsorbed on the plant root system in rather large amounts which are available for future use. This type of study should also be carried on in the field using tagged fertilizers to determine total requirements and storage capacity. In corn, for example, with its extensive root system during and subsequent to the period of maximum growth, it has been found that the plant cannot get a major share of the phosphorus needed to make a crop from application made at planting time. The root depth common to a nearly mature corn plant makes it obvious that phosphorus must be well distributed in the soil before planting in order that phosphorus requirements can be met and maximum yields obtained.

In determining the fertility status of soils, the radioactive isotope of phosphorus incorporated into the fertilizer proves useful. When a plant is presented with two sources of a given element at the same time, it will absorb from each in direct proportion to the amounts available. We then make one source the soil and the other the tagged fertilizer. The extent of dilution of the tagged fertilizer in the plant will then indicate the amount of available phosphorus already present in the soil.

Tagged Agricultural Chemicals

As previously pointed out in this article, large chemical molecules having a specific use in agriculture can be tagged radioactively by using a radioactive material in place of its stable isotope during the synthesis of the compound. With the aid of radiation detectors, it is then possible to follow the course or change in configuration of an agricultural chemical through the plant or animal. We can also determine coverage of a spray deposit, leaching rates, solubility of materials, penetration, and many other parameters by tagging the active compound.

At Oregon State College, under the direction of Joseph S. Butts, the mode of action of 2,4-D has been under investigation for some years. Very little was known earlier regarding the factors responsible for the difference in sensitivity of dicotyledonous plants over monocotyledonous plants to 2,4-dichlorophenoxyacetic acid (2,4-D). As is well known today, the broadleafed plant (dicotyledonous) is far more sensitive to 2,4-D than are the grasses, which fact makes the chemical extremely useful in weed control. Many factors have been investigated, for example the rate of absorption and translocation in susceptible plants as compared to grasses. Table 1 clearly demonstrates a lack of absorption of 2,4-D in grasses (3.1% in wheat after 3 days) as compared to broadleafed plants (51.1% in bean after 3 days).

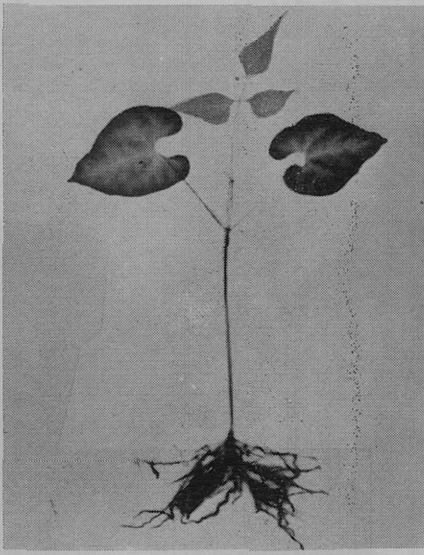
The rate of absorption also varies with plants, the tomato plant steadily increasing its absorption until the seventh day when 51.3% is absorbed. The reverse appears true in the pea plant which absorbs steadily decreasing amounts for some unaccountable reason. However the difference in rate of absorption cannot be taken as the primary effect in differences of plant sensitivity, as work has shown that for equal concentrations of 2,4-D in bean and oat plants, the growth of the bean plant is greatly retarded while the oat plant is not affected. Further studies have shown that the translocation of 2,4-D is more rapid in a susceptible plant than in a resistant one. Also, the applied 2,4-D is found to react with the plant substrate to form 2,4-D–protein complexes which have been suggested to be the products of a detoxification process. These complexes may act as an antimetabolite in the plant systems, although there is no real evidence to suggest they are responsible for the metabolic disturbances set up by herbicides.

Investigation has shown that 2,4-D induces marked changes, involving many plant constituents in the biochemical make-up of the cell. The most marked effect is a rapid depletion of carbohydrate reserves, such as starch and sugars. In addition, a change in the amount and distribution of plant nitrogen constituents, a disturbance of phosphorus and potassium metabolism, and a reduction in the rate of photosynthesis are also observed.

No definite primary action can be postulated as yet, for any of the systems investigated. Possibly some system exists which brings about the changes noted to date. That this system may be associated with photosynthesis has prompted some recent research at Oregon State College which studied the effect of 2,4-D on the incorporation of radioactive carbon dioxide into glutamic and aspartic acid. The experiment was carried on by exposing excised leaves of both normal and 2,4-D treated plants to radioactive carbon dioxide. The period of photosynthesis varied from 10 to 60 seconds to 24 hours after which the leaves were boiled in 80% alcohol and the extracts chromatographed separately by two-solvent systems of aqueous phenol and *n*-butanol–acetic acid–water solvent. Radioautograms were also prepared to show in what compounds the radioactive carbon appeared.

Results indicate generally that 2,4-D reduced the rate of photosynthesis by

Figure 3. Uptake of tagged CMU from soil



slowing the mechanism involved in the biochemical turnover of carbon or perhaps by blocking certain metabolic systems to cause an abnormal pathway of synthesis with carbon. Treated plants when compared to untreated show a reversal of activity in both oxalo succinic acid and citric acid. This might suggest that 2,4-D blocks the transformation of citric and oxalo succinic acid.

The mechanism of action of selective herbicides such as the phenoxyacetic acid type, carbamate type, and urea type might also be explained by postulating a biochemical difference between plants which are susceptible or resistant to such herbicides. Figure 3 shows that CMU [*N*(*p*-chlorophenyl)-*N*; *N'*-dimethyl urea] translocates very readily in the bean plant the tagged CMU having been placed in the nutrient solution for the radioautograph. Some doubt had previously existed that this urea compound, which is toxic to both dicotyledonous and monocotyledonous plants, was capable of moving through a plant system.

Table II lists a more practical use of tagged 2,4-D in plant work by comparing the absorption of 2,4-D under various concentrations of added wetting-agent. The table shows a marked increase in absorption efficiency when the 2,4-D solution contains 0.1% wetting agent. In the field, this knowledge would result in savings either by reducing the amount of 2,4-D or by obtaining sufficient weed control in one application through addition of this concentration of wetting agent to the spray mixture. Other experiments of a practical nature have demonstrated that optimum absorption of 2,4-D into a plant occurs when the spray solution concentration is approximately 1 part 2,4-D to 1000 parts water. Exceeding this concentration does not increase absorption into the plant.

The work reported here only covers some small proportion of the vast amount being accomplished with the aid of ionizing radiation either as such or in minute quantities for tracer studies. Some other larger research projects involve nutritional studies with animals by both the USDA and the University of Maryland where work has shown that the element molybdenum is essential to animals, that the true digestibility of phosphorus in alfalfa hay for lambs is 91% against 27% as previously believed, and that oral administration of cobalt to animals relieves a vitamin B_{22} deficiency in the most effective manner. Also discovered was the synthesis in the chicken of the amino acid cystine from inorganic sulfate. Therefore, cheap inorganic sulfate can be considered an important nutritional mineral.

Light on Photosynthesis

At the University of California, under Melvin Calvin, a rather extensive project to determine the fundamental processes involved in photosynthesis has been under way for several years. At first the role of water in this process was investigated using the heavier nonradioactive isotope of oxygen in water for the tracer. The oxygen evolved during the process of photosynthesis was enriched in oxygen-18 proving that the plant oxygen is derived from water rather than carbon dioxide. This also proved that hydrogen for carbohydrate synthesis arises from the plant water. The next step was to discover the specific process that goes on in the chemical reactions of carbon dioxide after the hydrogen is transferred into the system. In this process radioactive carbon (carbon-14) has enabled the drawing of a complete map of carbohydrate production. Essentially this process might be represented by the following equation $CO_2 + (H) \rightarrow (CH_2O)x$. The number (represented by x) of carbons in the molecule (CH_2O) has been found to be three in the first product isolated, then six, a split of the six-carbon sugar to four and two, combination of a four and three to form a seven-carbon sugar, and finally a loss of two carbons from the seven carbon sugar leaving one five, and forming another five by combining the two just split with another three. The rate of compound formation proceeds very rapidly, the first predominant material, phosphoglyceric acid appearing in less than 10 seconds.

To reduce one molecule of CO_2 in the photosynthetic carbon-reduction cycle there is required four equivalents of (H) and three molecules of adenine triphosphate. There is postulated the possibility that this energy requirement may be met to some extent by plant respiration which could supply some of the adenine triphosphate.

Further work under Prof. Calvin has also implicated thioctic acid in the fundamental process of photochemistry which has led to a new concept of the nature of the photochemical act as it occurs in the lamina of the subchloroplast structural units (grana). The possibility exists that the absorption of light creates, within the chlorophyll-containing layer, conduction electrons, one per quantum, which are separated from the remaining "holes" because of the structure of the lamina. The holes are trapped by donation of electrons from water molecules, while the electrons are accepted by the sulfur atoms of a thioctic acid compound to produce a dithiol which, in turn, can pass its hydrogen on to other carriers, ultimately to phosphoglyceric acid.

Future Potentialities

In considering the accomplishments in the field of agriculture made possible through the use of atomic energy, one can easily assume that the future holds many potentialities. The work in radiation genetics offers the possibility of new strains of plants resistant to disease coupled with increased yield. The

TABLE I. RATE OF ABSORPTION AND TRANSLOCATION OF CARBON-14–LABELED 2,4-D IN GREEN PLANTS

	DAYS HARVESTED AFTER TREATMENT			
Plants	**1 (%)**	**3 (%)**	**7 (%)**	**14 (%)**
Bean	40.7	51.1	49.1	53.6
Pea	14.8	10.4	3.5	. . .
Tomato	17.7	28.9	51.3	. . .
Corn	10.8	10.0	13.3	. . .
Wheat	. . .	3.1	4.7	. . .
Oat	. . .	3.5	2.0	. . .

TABLE II. EFFECT OF TWEEN-20 ON THE ADSORPTION AND TRANSLOCATION OF RADIOACTIVE 2,4-D IN BEAN PLANTS

Amount of Tween-20 Added (%)	Specific Activity of Stem Tissue (Counts/min./mg.)	Total Activity of Stem Tissue (counts/min.)	Absorption and Translocation (%)
None	289	89,460	8.0
0.1	1,486	445,700	36.4
0.5	1,307	458,940	37.5
1.0	1,591	466,050	38.0
2.5	2,003	614,450	50.0

NOTE: Each group consist of 15 plants; each plant received 50 micrograms radioactive 2,4-D, 7.5×10^5 counts/min.; all plants were harvested 124 hours after treatment.

fundamental studies on element uptake and mobility in plants offer a means for development of more effective techniques of fertilizer application and cultivation. Fundamental studies on agricultural chemicals offer not only more effective use of herbicides, insecticides, and fungicides but the real opportunity of developing tailor-made materials which are much more effective than present products.

The future potentialities concerned with a complete understanding of photosynthesis stagger the imagination. Directly, there is evidence that photosynthesis does not proceed through all the hours of sunlight, the plant apparently going into a rest phase at times through the day, and then proceeding again with its synthesis. If the limiting factors were understood, there is the possibility of creating shorter growing periods with resulting yield efficiencies. The most interesting possibility of a complete understanding of photosynthesis would be the direct use of chlorophyll and solar radiation for production of specific materials or as an energy source for a process.

Industry in general has now accepted the use of radioisotopes to further research programs. However, the tendency of industrial laboratories to use the practical or applied approach to a research problem or to the use of atomic energy is quite prevalent. In the development of new agricultural chemicals, as an example, the approach is usually one of screening every shelf and randomly synthesized chemical conceivable with the hope of a lucky find. This "find" is then further varied synthetically in every manner possible, hoping to increase its efficiency. While such screening programs have been effective to some degree, they are in reality only a "hit or miss" type of program and uncertain asto results.

In scanning the fundamental research now being accomplished, particularly in our universities and colleges, it appears that considerable essential knowledge of life processes has now been accumulated, at least insofar as applicable to the development of new agricultural chemicals is concerned. By this is meant the makeup and specific function of enzyme systems in fungi, bacteria, insects, and plants; the essential element requirements of biological forms; functioning of various plant auxins; and in general, the purpose and function of the many components of biological systems.

Tailor Made Agricultural Chemicals?

With this storehouse of new knowledge it is now perhaps conceivable to develop or tailor-make a chemical for a specific purpose. To develop an insecticide, fungicide, or similar material the offending organism should be carefully investigated and the weakest point in its life cycle selected for chemical attack. This point would vary, but for example it might involve an element on which the organism is critically dependent, the reproductive cycle in lower forms, or a specific metabolic pattern allowing no change. In any plan chosen the various steps from determining critical areas in the living form to the final finished agricultural chemical can be greatly aided and understood by the use of radioisotopes in the form of tagged materials.

As an example there is now overwhelming accumulations of evidence that the element iron is most essential in fundamental components making up the metabolic scheme in living organisms. E. J. Ordal of the University of Washington has observed that the enzyme hydrogenase, which is involved in the evolution, as well as the utilization of hydrogen by microorganisms is an iron-containing molybdoflavo protein. The fermentation of hypoxanthine and the decomposition of formate in anaerobic systems such as micrococcus lactilyticus are both inhibited by relatively low concentrations of metal complexing agents, and these inhibitions are relieved by ferrous ions. It is also found that when cells of *E. coli* are grown aerobically under conditions in which iron is the limiting factor, the enzyme hydrogenase is absent and iron is apparently present in cytochromes, catalase, etc., which function in aerobic growth.

Artificial cow used for study of milk formation by use of radioactive isotopes

This work along with that reported in the literature establishes iron as a very critical material in biological systems, which may partially explain the fungistatic and bacteriostatic action of many of the common laboratory metal-complexing agents. It is conceivable, then, that a material specifically synthesized as an iron-complexing agent, that will enter the environment of the offending organism under optimum conditions, might be an excellent fungistatic or bacteriostatic agent. This approach, offered purely as an example, could be aided with radioisotopes by adding radioactive iron (iron-59) to a culture of cells under such conditions that iron is a limiting factor.

Under these conditions it would be expected that the radioactive iron would go primarily into systems where it is vitally required and functional. The active components would thereby be labeled and could be separated and identified, and a specific metal-complexing agent synthesized to remove them from the organism or its environment.

Also easily accomplished is the determination of the metal complexing efficiency of the chemical under test. Separation of the active components would be accomplished with a known metal-complexing agent and this separation efficiency compared with experimental metal-complexing agents. By suitable separation of cell extract, cellular material, and external media the fractions of radioiron remaining in each can easily be determined using common laboratory counting equipment.

Much Information from One Experiment

The foregoing represents mainly a theoretical possibility but does convey the multitude of information to be gathered from the use of a single isotope in one experiment. Other applications in agricultural chemical research seem apparent. The inability of a potentially able fungicide or bactericide to gain entry to its intended site of action can often dismiss the compound as a useful material. This may be due to a lack of sufficient solubility in water to reach lethal concentrations in the liquid environment of the microorganism, or the material may be incompatible with the organism's environmental medium and precipitate or otherwise be rendered ineffective. If the site of action is within the cell the material might not be able to penetrate the cell membrane. Tagging the experimental material would provide data concerning all the above by simple separation techniques and counting of fractions wherefrom percentage incorporations can be calculated. An analog or homolog of the material could then be chosen that possessed either a greater degree of water solubility or characteristics that will permit a more intimate association of the material with the cell.

Defoliant Action Needs Study

In the field of herbicides much already has been covered concerning the selective hormone type of materials. It appears that little if any fundamental work using radioisotopes has been accomplished in the field of defoliant-type chemicals. Such materials are presumed to accelerate the formation of an abscission layer between the leaf and stem of a plant, causing the leaf to break away from the plant earlier than it would naturally. This layer is a formation of cells, quite brittle in character and may be formed through the action of a plant auxin. A number of chemicals including the xanthates and cyanamides will hasten formation of this layer either by an action of their own on the plant or by the stimulation of plant auxins. Either of the above chemicals could easily be tagged by using radioactive sulfur or radioactive calcium, respectively, in their synthesis. The material might be expected to move into the leaf and concentrate in the abscission layer causing the formation of the easily fractured cell layer.

Such movement readily could be ascertained by sectioning the stem longitudinally and exposing the layer to film. One might presume that the defoliating effect was primarily due to the chemical itself if no evidence of movement into the stem was observed. If movement into the stem without localization was observed, one might presume that the plant auxins caused the formation of an abscission layer to prevent the further entry of toxic material into the plant. Along with such data one would also determine in the same experiment much practical data on absorption under varying conditions of relative humidity, soil moisture, and other environmental factors.

In retrospect, one realizes that a notable and extremely useful tool has been added to the laboratory. The work already accomplished with radioisotopes assures an era ahead that is almost unlimited.

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PESTICIDES

PLANT NUTRIENTS AND REGULATORS

FOOD PROCESSING

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