ISOTOPES IN SOIL-PLANT NUTRITION STUDIES

Agriculture is dependent on soil for a variety of reasons, one of the most important being the fact that soil contains the elements which are essential to plant growth and can store nutrient elements (fertilizers) added from outside. Besides, soil provides a medium which can store water and make it available to plants without submerging the roots completely.

Study of soil characteristics and of processes by which plants take up nutrients from the soil is therefore extremely valuable in devising effective methods of farming. For example, such study can determine which fertilizer and how much of it should be applied to a particular soil, or when and how it should be applied. Similarly, a study of soil moisture can indicate the exact irrigation needs of a particular area.

Radioisotopes have greatly facilitated such investigations and are now being widely used in soil-plant nutrition research. A recent international symposium on the use of radioisotopes in soil-plant nutrition studies showed the varied ways in which isotopes can contribute to agricultural production by helping to investigate soil characteristics and soil-plant relationships. The symposium, jointly sponsored by the International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations, was held in Bombay from 26 February to 2 March 1962, at the invitation of the Government of India. It was attended by 52 scientists from 18 countries, including a number of the developing nations for which the subject is of basic economic importance.

Addressing the opening session of the symposium, Mr. S. K. Patil, India's Minister for Food and Agriculture, pointed out that improved methods of cultivation could play their part in increasing crop production only if the soil could supply plants with adequate nutrients, and it was therefore important to understand the intricate relationship between the soil and the plant. Until atomic tools were available, said Mr. Patil, direct experimental observation was difficult in most nutritional experiments, but radioisotopes seemed to have changed the situation.

The Chairman of the Indian Atomic Energy Commission, Dr. Homi J. Bhabha, gave an account of the various ways in which the Indian authorities were trying to promote the uses of isotopes in agricultural research and development. On behalf of the sponsoring organizations, Dr. Bernhard Gross, Director of IAEA's Division of Scientific and Technical Information, pointed out that isotopes could play a useful role in investigating the characteristics of plant nutrients in the soil, in measuring soil moisture, in studying the uptake of nutrients by plants and in devising efficient methods of fertilizer application.

All these subjects were discussed at the symposium, and leading experts in the field reported on the results of their research and experiments. There were eight scientific sessions, the first three of which dealt with applications of isotopes in the study of soil chemistry and physics, while the next two were concerned with isotope uses in studying the uptake of nutrient elements by plants from the soil. Biological measurement of soil characteristics (that is, by studying the plants themselves with the help of isotopes) was discussed at the sixth and seventh sessions, while the final session was devoted to the role of isotopes in fertilizer usage.

Soil Chemistry

Perhaps the most successful use of isotopes in soil research has been in studying the chemical properties of soil, especially in estimating the amount of nutrient elements available to plants grown on a particular soil. Several papers presented at the Bombay symposium dealt with the chemical constituents and properties of soil in relation to plant requirements. Three scientists from the University of Goettingen, Germany (B. Ulrich, H. Lin and H. Karapurkar), attempted to describe the process of phosphate dissolution from the solid phase into the soil solution

Dr. Homi J. Bhabha, Chairman of the Indian Atomic Energy Commission, addressing the opening session of the symposium. Others in the picture, from right to left: Mr. S.K. Patil, India's Minister for Food and Agriculture, and Dr. Knut Mikaelsen (FAO) and Dr. Maurice Fried (IAEA), Scientific Secretaries of the symposium

and the subsequent uptake of phosphate from the solution by the plant. Three scientists from the USA (M. E. Harward, T. T. Chao and S. C. Fang), on the other hand, discussed soil properties and constituents in relation to processes involved in the retention of sulphate by soils. Three French scientists (L. Soubies, R. Gadet and F. Fourcassie) described the motion of nitrates to the upper layers of the soil during the summer months. From their studies, they concluded that nitrogenous fertilizers must be placed at a depth of more than 15 cm if the climate is such that a hot, dry spell may occur during the growth season.

An interesting subject discussed at the meeting is the effect of ionizing radiation on the chemical properties of soils. Irradiation is known to sterilize the soil and there is a good deal of current interest in the use of radiation for the eradication of organisms in the soil which are harmful to plant life. The effects of such operations on the nutrient elements in the soil have, however, not yet been widely studied. H. J. M. Bowen, of the Wantage Research Laboratory, UK, reported on a series of experiments to study the effects of radiation on the availability of certain nutrients in the soil. The effects, it had been found, were comparatively mild with most nutrients. Since sensitivity towards radiation greatly varies between different organisms, use of different levels of radiation could therefore help in differentiating the effects of different organisms on soil fertility, with the minimum effect on the balance of nutrients.

Two Indian scientists, A. R. Gopal-Ayengar and K. B. Mistry, gave an account of the radioactivity of plants grown on the west coast of Kerala State and parts of Madras State in South India where the soil has a high concentration of radioactive minerals in the form of monazite, the thorium content of the monazite in some of these areas being the highest in the world. They found that of all the radioisotopes in the thorium family (thorium and its daughter products) the highest content in the plants studied was of radium-224 and thorium-228, and pointed out that in view of their long half-lives these isotopes constituted a potential hazard by their presence in biological material.

Physical Characteristics

Certain physical characteristics of soils, such as moisture, temperature and aeration, have decisive effects on plant growth, and radioisotope techniques are being developed for investigating these properties. The greatest success has been achieved with the study of soil moisture, which - for purposes of agriculture - is the most important physical property of soil.

Water is essential to plant growth not only because it plays a part in various life processes but also because it brings the nutrient elements into solution, the form in which plants can utilize them. Hence arises the importance of the best possible use of available water supply, which in turn depends on an accurate measurement of the moisture content of a particular soil.

A simple yet accurate method involving radioisotopes has been developed for the measurement of soil moisture. The method is based on the ability of hydrogen atoms to slow down the speed of neutrons, and since water is the main hydrogen-containing substance in soil, reduction of neutron speed in soil is related to its water content. The device based on this principle is known as a "neutron moisture meter" and consists of a source of fast neutrons which is placed into the soil or on the soil surface. The neutrons which strike hydrogen atoms in the water present in the soil lose speed and these slow neutrons are deflected back to a registering meter placed near the neutron source. A measurement of the slow neutrons thus becomes a measurement of soil moisture.

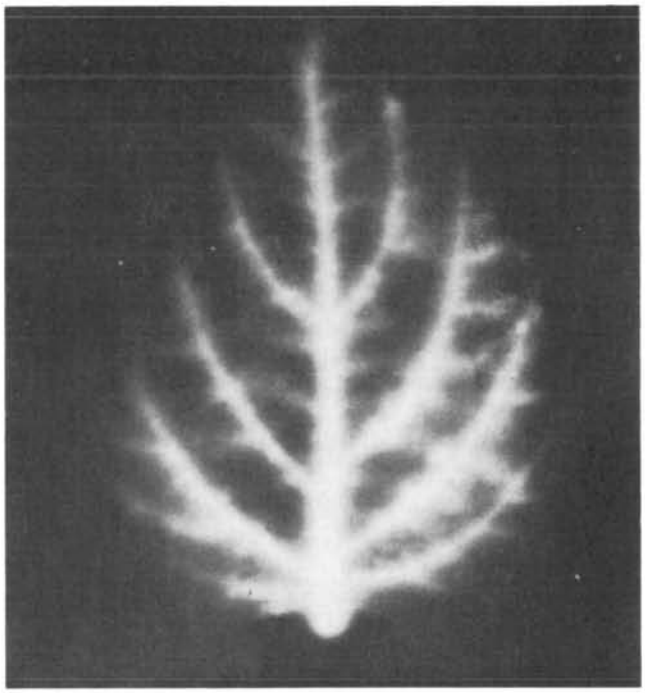
Several papers on this method of measuring soil moisture were presented at the symposium. A paper by four French scientists (C. Andrieux, L. Buscarlet, J. Guitton and B. Mérite) described a prototype neutron device made by the French Atomic Energy Commission, which, they said, was suitable for mass production and had already been put to practical application in Tunisia. J. Damagnez, a French scientist seconded to the Tunisian Government, explained the influence of several factors, such as the nature of the soil and its apparent density, on the counting rate of slow neutrons with a neutron moisture meter. V. A. Emelyanov and V. I. Osipov, from the USSR, dealt with the effect of the mineralogical composition of the soil on neutron moisture meter readings.

S. V. Nerpin and A. M. Globus, also of the USSR, presented a paper on the thermodynamics and kinetics of soil moisture and narrated how the theoretical ideas on the subject had been experimentally tested with radioactive tracers. A paper by two other Soviet scientists, M. P. Volarovich and N. V. Churaev, reported on results of research on the hydrophysical characteristics of peat and on the processes involved in the movement of moisture in peaty soils.

Uptake and Translocation of Nutrients

Processes involved in the uptake and translocation of nutrient elements by plants are being investigated with radioisotopes, and the results of such investigations were reported in a number of papers presented at the symposium.

H. Ziegler, U. Luettge and J. Weigl, from the Federal Republic of Germany, gave an account of experiments in which the uptake of radioactive sodium and radioactive calcium by roots of seedlings had been studied by microautoradiography. H. H. Wiebe and R. L. Smith, from the USA, presented a paper on the influence of bicarbonate on the movement of ions (the form in which elements are taken up by plants) into the root, while in another paper they discussed the influence of the lack of moisture on the translocation of nutrient elements in plants, showing that growth might be limited by reduced translocation under drought conditions.



This picture, which is a radioautograph of a coleus plant showing the distribution of radioactive phosphorus through the veins of the leaf, illustrates one of the radioisotope applications in the study of plant nutrition (Photo Brookhaven National Laboratory)

S. S. Shain and V. A. Shirshov, from the USSR, gave an account of the movement of phosphorus, calcium and sulphur between herbaceous plants through their root systems. The experiments reported by them showed that 80% or more of the radioactive isotopes of these elements and the stable isotope of nitrogen introduced into plants through roots or leaves pass out through the roots during the first few days, into the soil, sand or water medium. Thereupon, they are again absorbed, both by the roots of the plants to which they were originally administered, and by the roots of other, immediately adjacent, plants. The process repeats itself and thus spreads to plants further away from the original source.

Two American scientists, H. B. Tukey Sr. and H. B. Tukey Jr., referred to the fact, as demonstrated with the help of radioisotopes, that aboveground plant parts, including leaves, stems and fruits, are able to absorb nutrients applied to them, and said that it naturally followed that these parts might also lose materials by the leaching action of water or other aqueous solutions. In fact, they provided some evidence of this from the results of studies made with radioisotopes.

Measurement of Available Phosphorus

One of the most widely established applications of radioisotopes in soil-plant nutrition studies is in estimating the amount of phosphorus in the soil that is of equal availability to that in the fertilizer for plants. This amount, as distinct from the total amount of phosphorus contained in the soil, is known as the "A" value, a factor of great importance in determining the amount of phosphate fertilizer that should be applied to a particular soil.

The basic method of determining the "A" value with the help of radioisotopes can be described in fairly simple terms. If some plants are grown on a sample soil to which a known amount of radioactive phosphorus has been applied, a measurement of the phosphorus-31 (stable) and phosphorus-32 (radioactive) taken up by the plants will show how much phosphate has come from the radioactive fertilizer applied and how much from the phosphorus naturally present in the soil. Since the amount of phosphorus-31 and phosphorus-32 in the fertilizer added to the soil is already known, the ratio of the specific activities of plant and fertilizer phosphate will indicate the amount of phosphorus in the soil of equal availability as that in the fertilizer.

Scientists at the Bombay symposium discussed various refinements in this method and reported on the results of investigations carried out on different types of soil under different experimental conditions. For example, D. A. Rennie and E. D. Spratt, of the USA, explained how the placement of a "tagged" phosphorus standard with the seed could indicate not only the amount of chemically available soil phosphorus but also the relative amount of phosphorus within the root zone. M. A. Abdel Salam and S. Hashish, from the United Arab Republic, reported on experiments to study the effect of varying moisture levels in desert soils on the radiophosphorus uptake by plants.

E. Bottini (Italy) reported on a new method of studying phosphate nutrition, based on the competition for nourishment between leaves and roots and, more specifically, on the rate of displacement of radiophosphorus in a plant. Tracer studies with radiophosphorus-labelled fertilizers carried out in Brazil were described by two scientists from that country, L. N. Menard and E. Malavolta. Three experts from Argentina, A. H. Merzari, R. A. Ghelfi and E. O. Brenzoni, discussed a technique for determining the labile phosphorus content of soils by measuring the uptake of radiophosphorus by certain microorganisms instead of by plants. They maintained that the technique had several advantages over the plant method; for example, it took less time and the number of trials could be increased very easily.

K. B. Mistry (India) gave an account of experiments conducted on three different types of soil in an attempt to understand the residual effects of phosphate fertilizers. C. G. Lamm (Denmark) presented an analysis of the factors affecting the ratio in plants of a nutrient derived from the soil and a fertilizer.

Fertilizer Usage

At the last session of the symposium, L. A. Dean (USA) presented a general review of radioisotope applications in the study of fertilizer usage. He pointed

out that problems relating to the efficiency of fertilizer applications, comparison of fertilizer materials, rate, time and placement of fertilizers, influence of soils and crops on fertilizer utilization and soil fertility evaluation had been under consideration for many years, but prior to the advent of isotopic techniques the only criteria of fertilizer behaviour were growth responses and changes in the chemical composition of plants. The basic principles for applying isotopes to the study of these problems were first discussed about 15 years ago, and since then, in the United States alone, approximately 1000 field and greenhouse experiments had been conducted with fertilizers labelled with radioisotopes. Similar experiments were being conducted in other countries as well.

The experiments, Dr. Dean explained, involved two principles of radioactive tracer techniques, namely the gross transfer of ions from a specific source and the method of isotope dilution. The amount of a radioisotope found in a plant grown on a soil to which a labelled fertilizer has been added represents the gross transfer of the isotope from the fertilizer to the plant, from which it is possible to deduce the total amount of nutrient delivered from the fertilizer into the plant. The basic principle of the method of isotope dilution consists of incorporating a known amount of a labelled test substance in the material to be studied, isolating some fraction of the system when isotopic equilibrium has been obtained and determining its specific activity.

Several investigators, Dr. Dean said, had proposed additional applications of the principle of isotope dilution to the estimation of the amounts of available nutrient in soil. The simplest concept had been proposed by Dr. Dean himself and Dr. Maurice Fried, now a senior member of IAEA's scientific staff and scientific secretary of the Bombay symposium. They had assumed - as explained earlier in this article in connection with the basic principle of estimating the amount of available phosphorus in soil - that a plant confronted with two sources of nutrient, the soil and the fertilizer, would absorb the nutrient in direct proportion to the amount available. One of the interesting consequences of this assumption, said Dr. Dean, was that when increasing amounts of nutrient were added to a soil as fertilizer, the delivery capacity of the soil itself ("A" value) remained constant. This had been experimentally verified in the case of several nutrients.

Dr. Dean pointed out that the success of research with labelled fertilizers depended, to a large extent, on the quality and specifications of these materials. The radioisotope must be so incorporated in the fertilizer that it is uniformly distributed; the fertilizers must also meet certain specifications as to chemical make-up and physical form and should be comparable to fertilizers that are commercially available.

Other topics discussed by Dr. Dean included the comparative merits of field and greenhouse experiments. The results obtained from a field experiment, he said, related to specific locations, crops, seasons, climates and soils, and one was then faced with the problem of generalizing from these specific results which were influenced by many unmeasured variables. Greenhouse techniques permitted control over many of the variables encountered in the field. It must, on the other hand, be recognized that the results of greenhouse experiments may not always be extrapolated for direct practical application.

The symposium also heard several papers dealing with more specific problems of isotope applications to the investigation of fertilizer usage. Apart from contributions in the form of original papers, much valuable information was given in the course of discussions on each topic.

The following scientists presided over the individual sessions of the symposium: S. Ahmed (Pakistan), H. J. M. Bowen (UK), L. A. Dean (USA), A. R. Gopal-Ayengar (India), A. H. Merzari (Argentina), S. Nerpin (USSR) and H. W. Scharpenseel (Federal Republic of Germany).