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**In 1982, the name of the International Superphosphate Manufacturers' Associations (ISMA) was changed to International Fertilizer Industry Association (IFA).*

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REPORT ON INVESTIGATIONS ON THE USE OF RADIOACTIVE ISOTOPES IN AGRICULTURAL RESEARCH

presented to the International Conference of the United Nations on " The Peaceful Uses of Atomic Energy", Geneva, August 1955,

by L.J. CARPENTIER (I.S.M.A.)

Among the many papers presented and discussed at this conference, one whole section dealt with the use of Atomic Energy in Agriculture and in Biology. These papers have been collected in vol. XII of the Proceedings, a work of considerable size, under the following main headings :

1) Generalities on isotopes in Medicine, Biology and Agriculture

2) Radiation-induced genetic changes and crop improvement

3) Radioactive and ionising radiations in agriculture - Tracer studies

4) Radioactive isotopes in physiology and biochemistry

We shall not here examine these sections in turn, and shall leave out sections 2 and 4, thus limiting the discussion to problems of plant nutrition and the use of fertilisers.

This present report will be divided into two chapters, the first of a general nature, the second dealing with fertilisation, especially the foliar applications of fertilisers and the use of phosphoric acid.

I - POSSIBILITIES OFFERED BY RADIOACTIVE ISOTOPES IN AGRICULTURE

In the general report presented by F.A.O. (3) which indicated the main spheres of application of atomic energy in agriculture, the role of radioactive elements is envisaged from two points of view : the energy set free by their disintegration, that is, atomic energy in the strict sense, and also the characteristic radiations which they emit.

Atomic energy in itself as applied to agriculture is of no specific character. Its spread will make available to farmers cheaper and more easily accessible power, since the construction of a reactor is in no way bound up with geographical considerations (presence of a coal basin or a river), but can be undertaken almost anywhere.

The role of the radiations can be considered from two points of view :

Their direct effect on the bodies on which they fall - genetic mutations caused by radiations (10), control of crop pests, of parasites on the harvests, preservation of foodstuffs etc. (13) -

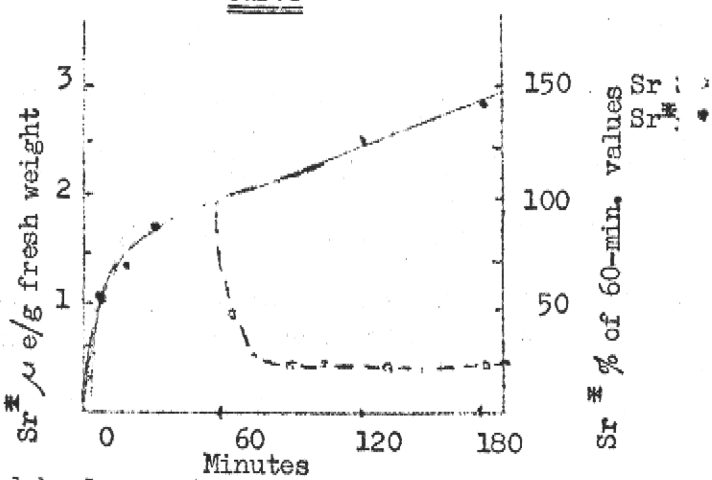
Their indirect effect, that is, the possibility of keeping track of a mineral element thanks to the presence of its radioactive isotope . This latter aspect is of increasing importance in biological, zootechnical and agricultural research. We shall later give attention to this aspect and shall attempt primarily to show the part played by tracers first in plant physiology, then in soil science.

A) Radioactive elements in plant physiology

The radioactive isotope of carbon, C^{14}, has been much used in research on photosynthesis (7, 8). It was thus observed that the saccharose of sugarbeet leaves is formed very soon after the absorption of the CO_2. The products of photosynthesis then move rapidly towards the roots, at the level of which they meet those assimilated by the roots.

The use of radioisotopes has also enabled explanation of the phenomenon of ionic absorption by roots (2). It is in fact a question of exchanges, as the absorption curve of Sr^{89} shows. This curve is divisible into two sections representing two successive phases. The first, corresponding to the very steep section of the curve, is a rapid absorption of ions which is completed after about 30 mn, the second is a much slower absorption - the curve looks linear - which never attains equilibrium.

Curve



Uptake of Sr^{89} by excised barley roots and its loss to non-radioactive Sr.

The ions of the first category, unlike those of the second, are immediately exchangeable with the environment. In the first case, we meet very mobile surface ions, and in the second case, much more stable ions which have deeply penetrated into the root tissues. There can occur simultaneously a loss of ions of the exchangeable fraction into the external medium and an entry of similar ions into the roots. In this respect the latter thus act as ion exchangers.

Further, research carried out with S^{35} on roots placed in water enabled to realize that the concentration of the ions of the external part of the roots is the same as that in the surrounding medium.

With these isotopes, it is possible to follow the displacement of ions through the conducting tissues (6). Thus, with tagged sodium iodide NaI^{131}, American authors have measured the rate of rise of iodine in the oak. It varies from 45 to 90 cm/mn when the atmosphere is quite dry and in full sunlight but can drop to 6-12 cm in moist overcast weather. It is almost zero during winter.

Further, the speed of displacement or "translocation" (8) of assimilated nutrients reaches 72 cm/hour in young plants, decreasing to 50 to 30 cm in older plants.

We shall bring to an end here this enumeration of the many questions in plant physiology which can be closely studied by the use of radioisotopes : evolution and displacement of organic products, in particular amino-acids and proteins etc. We cannot here discuss all these questions, which are treated in detail in the Proceedings.

B) Radioactive elements and the study of the soil

Apart from problems connected with fertilising, which is the theme of the next chapter, radioactive isotopes have enabled a number of successful investigations on other subjects, for example the measurement of soil moisture with neutrons, which undergo a maximum loss of energy when they meet a hydrogen atom (13). In Japan they have studied the injurious effect of hydrogen sulphide in certain low-lying ricefields (9-10) with the help of S^{35}.

But it is above all the movement of ions in the soil which has been studied by means of radioisotopes : it has been possible to detect by the use of Ca^{45} for example that calcium, unlike phosphorus, is displaced in a continuous manner.

II - THE ROLE OF RADIOACTIVE ELEMENTS IN THE STUDY OF FERTILISING

The spread of radioactive isotopes has opened immense vistas in this sphere, in particular for fertiliser experiments : comparison of several sources of the same nutrient element, method and time of application etc. In fact, as P^{32} is the most easily available radioactive element, it is phosphate-fertiliser studies which have benefited most from this new technique. We shall see the results of this later.

As regards the comparison of different fertilisers, Sokolov (12) claims to have simplified considerably the experimental methodology by using what he calls the technique of "selective assimilation". On mixing in the same pot two fertilisers to be compared, one of the two being tagged, the radioactivity emitted by the plant indicates its relative degree of preference for the two products. He himself, however, admits that repetitions are necessary, and that this method is open to criticism when the fertilisers have approximately equal fertilising values.

Among the few particular matters dealt with, let us quote the paper by a Russian author on cobalt, summarising his work with Co^{60} (4) with which he has studied particularly the effect of liming on the content of assimilable Co in the soil.

A) Foliar applications

A complete paper has been devoted to this question (5). Radioisotopes have shown that leaves always absorb small amounts of nutrient elements and that the bark of trees is also slightly absorbent (14). The passage of nutrient elements from the leaves appears to be faster than that of elements absorbed by the roots.

Nitrogen, phosphorus, potash and rubidium, on foliar application pass freely into the whole plant, both upwards and downwards. In this respect, there is no difference from root absorption. The same does not hold for calcium, strontium and barium, which do not pass downwards. Phosphorus has a tendency to accumulate in the meristem. Its rate of absorption is much higher than for roots (up to 95 %) and it has been proved that it would be possible to satisfy more than 25 % of the requirement of the plant for this element by foliar application.

In what form should phosphoric acid be applied ? Various phosphates and a 0.3 % solution of orthophosphoric acid have been compared, the latter form appearing more suitable.

Certain factors improve the absorbing properties of the leaves : the addition of wetting agents which spread a liquid film over the whole leaf and thus cause a more regular distribution of the fertiliser, also light and temperature, which is optimal at about 21º. The two sides of the leaf and the petiole have equal absorbing properties ; on the other hand, the greater or lesser abundance of stomata does not appear to have any effect on this phenomenon. This is explained in terms of the process operating, analogous to that of assimilation by roots, an ionic exchange.

B) The role of P^{32} in agricultural research

The first problem which agronomists have attempted to solve with the help of P^{32} is the assimilation of the P_2O_5 of a fertiliser, that is, the proportions of the P_2O_5 absorbed by the plant that are derived from fertiliser and from the soil. This leads in turn to attempt to discover the causes of the phenomenon of the fixation of phosphoric acid in cultivated soils. Some authors (13) have found that the plant assimilates relatively little P_2O_5 from fertiliser at the start of its growth, more from the 2nd to the 6th week, and less after the 8th week.

Scott Russell and his colleagues (11) have tried to define the available P_2O_5 of the soil and state, on the basis of their research with P^{32}, that this idea is wrong. They have established a formula for calculating the amount of "labile" or isotopically exchangeable phosphate present in the soil at a time t :

$$Et = \frac{x_t}{y_t} \quad y - x$$

x and y being the amounts of P^{31} and P^{32} present in the soil solution at the start, and x_t and y_t those present at the time t.

They have derived from it another equation for determining the amount of phosphate adsorbed by the soil colloids.

$$S_t = x - x_t$$

They then compared the figures and the curves obtained for E_t and those given by calculation of Larsen's value L, the definition of which is given in his paper presented to the Joint Technical and Agricultural Meeting at Lausanne (seePA/149). They found with P^{32} a linear relationship between the rate of absorption of P_2O_5 in a soil and the E and L values, but the amount absorbed represents only a small part of the "labile" phosphate. This rate of absorption is in inverse ratio to the absorption of P from the fertiliser by the soil. There thus exists a linear relationship between E and the amount of phosphorus added in the fertiliser, and this relationship is dependent on the plant chosen.

The use of P^{32} made it possible at the same time to confirm Schofield's ideas on the fixation of phosphate ions by Fe ions, according to which the reciprocal effect of these two ions is manifested within the interior of the roots. In effect, the addition of Fe to the soil induces in the plant an increase in the P content of the roots and a decrease in that of the shoot, whether the Fe is applied before or at the same time as the phosphorus. The authors believe that an organic complex may be formed, including iron and phosphorus. They suggest the following formula for this complex :

$$RFeH_2PO_4$$

They have not, however, detected the same process for aluminium.

They have concluded that the concept of the soil available phosphorus should be dropped and replaced by that of "phosphate potential" of the soil, that is, the amount of phosphate capable of being put at the disposal of the plant, which depends on a certain number of factors inherent in the nature of the soil. These ideas agree with those expressed by Barbier in a lecture before the Agricultural Advisory Commission, published in the Bulletin de Documentation nº 17.

The Russian Sokolov does not appear to be of the same opinion, and claims that the fixation of phosphoric acid by a soil is irreversible. Further, he gives a formula for determining the assimilable phosphorus of the soil.

$$x = \frac{P \times 100}{K}$$

P = amount of phosphorus absorbed by the plant
K = % of P^{32} utilized

But he accepts, however, that this concept of available phosphorus must be revised in the light of the results of experiments done with P^{32}.

Method of applying phosphate fertilisers

The use of P^{32} has confirmed the observations made by the conventional methods on the placement of P_2O_5 . When the fertiliser is placed near the seed, the young plant at first utilizes it but, as its roots grow, the plant turns increasingly to the phosphorus of the soil (1).

For the same reason, when two granular superphosphates of different granule size are compared after placement (5), absorption is initially most rapid from the small granules, while later the reverse holds.

It is possible to conceive and undertake all sorts of experiments on the method and time of application. Many authors of these papers cite experiments which agree with the observations made previously.

C O N C L U S I O N

In the field which particularly interests us, that of the use of fertilisers, it is clear that radioisotopes will play an increasingly important part. All the examples given by the authors of these papers prove this abundantly, but the majority of them have up till now used only P^{32}. Glad though we may be to see research into phosphate fertilising so advanced by this means, we must hope also that in the near future all the nutrient elements will profit from this technique, so that the extremely important study of the interaction between the various elements and of fertiliser balance can be followed up.

We have seen that the use of P^{32} has enabled an attack in fields which have been accepted everywhere, concerning the explanation of the complex phenomenon of phosphoric-acid fixation for example.

As was said in the introduction, it was not desired here to summarize all the papers presented at Geneva, but only to indicate the main ideas put forward at this conference that could be of use to the superphosphate industry.

N.B. For detailed information concerning these papers, our correspondents should contact the Office of the Agricultural Committee in Paris, where vol. 12 of the Proceedings is held.

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