ROLE OF ISOTOPES IN MINERAL PLANT NUTRITION STUDIES

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ABSTRACT

Over the past three decades, the Soil Fertility, Irrigation and Crop Production Section of the Joint FAO/IAEA. Division has conducted several International Co-ordinated Research Programmes on the use of isotope techniques for developing efficient fertilizer management practices and enhancing biological nitrogen fixation. The research approaches and the role of isotopes in these programmes are highlighted. For future studies it is postulated that improvement of soil fertility and plant nutrition efficiency can be achieved through an integrated approach of nutrient and water management in the cropping systems under study.

Key words: fertilizer, plant nutrient, water, nitrogen fixation, isotopes, crop production.

INTRODUCTION

Sustainable agricultural development has one overriding goal: to produce adequate food for the ever increasing world's population without damaging the natural resources upon which the future generations depend. This is a great challenge since most increases in food production in the coming years will be from the intensification of agriculture on the existing, limited arable land, through cropping intensity and higher unitary crop yields. Improved efficiency of nutrient cycling and water use are among the major strategies proposed for these increases (Biswas, 1994; Hera, 1996).

In most industrialized countries, the continuous application of fertilizers in intensive cropping production systems has resulted in net positive nutrient balances and a consequent soil fertility build-up with potential environmental hazards. The opposite occurs in most soils of the tropics where there is net mining of soil nutrient due to crop harvest removal and erosion (Sanchez, 1994).

Although fertilizers are an essential input for increasing crop production, their cost is often too high and their supplies are also very limited in developing countries (Bowen and Zapata, 1991; Hera, 1996). In this context, there is a need for developing integrated plant nutrition systems through optimal use of all possible source of nutrients, inorganic and organic, in order to sustain increased crop productivity and simultaneously enhance nutrient cycling and soil and water conservation (Hera, 1995; Roy, 1995).

Isotopes are a very powerful tool for measuring the nutrient uptake from various fertilizer sources, for studying the processes that influence the efficiency of the applied fertilizers and for assessing the fate of the non-efficient fraction, for instance to minimize losses of nutrients and water from the agro-ecosystem under study (Zapata and Hera, 1995)

INTERNATIONAL FAO/IAEA COORDINATED RESEARCH PROGRAMMES ON THE USE OF ISOTOPE TECHNIQUES IN NUTRIENT USE EFFICIENCY

In 1964 two United Nations organizations decided to join forces and established the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture at the IAEA Headquarters in Vienna. The mission of the Division is to strengthen capacity for using nuclear methods to improve technologies for sustainable food security and to disseminate these through international co-operation in research, training and other outreach activities in Member Countries of FAO and IAEA. The following main services are provided: coordination and support of research, technical management of field Technical Co-operation projects, training of local scientists, laboratory support and dissemination of scientific information.

The Joint FAO/IAEA Programme in Food and Agriculture is implemented through the following five Sections of the Joint FAO/IAEA Division: Soil and Water Management and Crop Nutrition, Plant Breeding and Genetics, Animal Production and Health, Insect and Pest Control, Food and Environ-

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mental Protection and the associated FAO/IAEA Agriculture and Biotechnology Laboratory situated at Seibersdorf.

Since the creation of the Joint FAO/IAEA Division, the Soil and Water Management and Crop Nutrition Section, formerly Soil Fertility, Irrigation and Crop Production Section, with the support of the Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory has promoted research, development and transfer of nuclear methods along three main subject areas: a) fertilizer use efficiency, b) biological nitrogen fixation and c) water use efficiency. This report will focus on the first two above mentioned areas.

Efficient use of chemical fertilizers

Only a fraction of the fertilizer applied to the soil is taken up by the crop. The rest either remains in the soil or is lost from the rooting zone through several processes. It is thus necessary to obtain information on the relative merits of different fertilization practices such as times of application, methods of placement and sources of fertilizer. Field experiments using fertilizers labelled with stable and radioactive isotopes provide a direct and quik means of obtaining conclusive answers to these questions. By isotope dilution it is possible to determine directly the proportion of nutrient taken up from the labelled fertilizer by the crop and, if the total nutrient uptake is measured, the amount of nutrient supplied by the fertilizer can be determined.

Over the past three decades the Soil Fertility, Irrigation and Crop Production Section of the Joint FAO/IAEA Division has conducted several international Co-ordinated Research Programmes on the use of isotope techniques for developing efficient fertilizer management practices of major food grain crops such as rice, maize and wheat (Hera, 1995). The main goal of these programmes was to achieve higher and more stable grain yields by optimizing the uptake of nutrients from applied fertilizers. The early programmes saw the first use of isotopes in large-scale field experimentation, with nutrient uptake and fertilizer recovery by plants being the dominant approach (Zapata and Hera, 1995).

The findings from these Programmes were used in the preparation of FAO Fertilizer Bulletin No.3 “Maximizing the Efficiency of Fertilizer Use” (1980). The adoption of improved fertilizer practices in many countries around the world has resulted in savings of fertilizers worth many milions of dollars each year.

Follow-up Programmes were devoted to assessing the fate of applied fertilizer N in different cropping systems. A balance sheet approach for the applied N-15 labelled fertilizer was utilized taking into account the N-15 recovered in the plant and the soil profile to a given depth. The remaining fraction (unaccounted for) was considered as lost from the soil-plant system. Moreover, the use of highly enriched N-15 labelled fertilizers enabled the study of the carry-over or residual effect of applied fertilizer N to a subsequent crop in a cropping sequence or rotation. This approach was adopted, e.g., within the framework of the CRP on Soil N as Fertilizer or Pollutant (1975-1983).

A great deal of information on the fate of fertilizer N in different agro-ecosystems was accumulated. The total recovery values in plant and soil varied according to the growing season, crop and specific soil/water and fertilizer management conditions. On the average, total fertilizer N recovery values were of the order of 70-90% but also low values of 25-50% were found in non-efficient systems leading not only to low yields but also environmental pollution (IAEA, 1980, 1984).

A technique based on injection of a P-32 labelled solution to the soil was developed at the Laboratory and utilized within the framework of a CRP (1967-1972) to determine the root activity patterns of various tropical tree crops. As applications of fertilizer in close proximity to the zone of the highest root activity and at a time when the roots are most active can be expected to result in a higher fertilizer nutrient uptake by the crop, information on the root activity distribution pattern is an essential pre-requisite for the formulation of sound fertilizer practices in tree crop plantations (IAEA, 1975).

Recent developments in sampling analytical techniques and instrumentation for measuring nitrogen and carbon isotopic ratios have made possible to extend further these isotopic studies to tree plantations. Initial work focussed on developing isotopic labelling and sampling techniques for measuring not only storage in several parts of tree but also cycling of nitrogen within the tree as affected by various management practices. Recent studies in Malaysia (tree plantations) and Chile (orchard fruit trees) include seasonal movement of fertilizer N in the soil profile accompanied by water balances.

Although it is well known that considerable genotypic variation in mineral nutrient use efficiency exists, this approach has been little exploited in breeding and selection programmes (Sattelmacher et al., 1994). Such germplasm impovement to soil constraints is strategic for sustainability and multidisciplinary in nature as it should involve breeders, soil scientists and plant physiologists.

This approach was the basis of a CRP funded by the Swedish International Development Authority, to identify genotypes, annual food crops and tree species for high water and phosphate use efficiency. Research involved the identification of genotypic differences in nutrient and water use efficiency for the selected crop species and then study of the key components of such efficiency in order to assist plant breeders in developing appropriate selection criteria. Emphasis were on Africa and low-input conditions.

Superior genotypes/provenances were identified with the important finding that high efficiency in phosphate or water use was not always translated into better yield. Root length, density of plants play a crucial role in determining the efficiency of uptake of phosphorus or water from the soil. It is expected that these findings will be utilized at the local level and in further CRPs (IAEA, 1996).

Efficient use of alternative nutrient sources

The high costs of chemical fertilizers and their often limited supplies are the main limiting factors to securing adequate agricultural production in developing countries. Hence, it is appropriate to look for alternative nutrient sources which are locally available and/or less expensive.

In several CRPs great emphasis has been placed on enhancing the extra-input of biological nitrogen fixation (BNF). The contribution of legume N fixation to the nitrogen economy of both soils and plants was investigated as an alternative to chemical fertilizer N. The BNF programmes, initiated some twenty years ago focused on grain legumes and the development of the N-15 methodology to estimate nitrogen fixation in the field. These programmes were followed by others in which BNF in forage and tree legumes, and *Azolla*, was quantified. Recent programmes emphasize the enhancement of nitrogen fixation in selected grain legumes through the identification of superior genotypes for nitrogen fixation (Hardarson, 1994).

The contribution of BNF by *Azzolla* to rice-based cropping systems was studied in a CRP on isotopic studies of nitrogen fixation and nitrogen cycling by blue-green algae and *Azolla* (1985-1989) in which ways of integrating the use of urea with *Azolla* to maximize rice yield with minimum inputs of urea were investigated.

The N-15 isotope dilution technique showed that up to 80% of N accumulated by *Azolla* may be derived from N fixation, depending on the *Azolla* species, and environmental conditions. Results from several locations and years showed that *Azolla* is as effective a source of N for rice as urea (Kumarasinghe and Eskew, 1993). Nevertheless, widespread uilization of *Azolla* is still limited by socio-economic factors, especially availability of hand-labour and by the extra management inputs that are necessary.

A similar approach is being followed in an ongoing CRP on the use of nuclear and related techniques for evaluating the agronomic effectiveness of P fertilizers, in particular rock phosphates. Rock phosphate deposits exist in many dveloping countries of Asia, Africa and Latin America, offering possible inexpensive alternative means of supplying P to crops in acid soils. Some rock phosphates are better (more reactive) than others and several factors will influence their capability to supply P to crops (Zapata and Axmann, 1991). Also, quantifying the P availability of soils amended with rock phosphates under a variety of crop management and environmental conditions is imperative for making appropriate recommendations to obtain maximum agronomic and economic benefits (Zapata et al., 1994).

FUTURE PROSPECTS IN THE USE OF ISOTOPE TECHNIQUES FOR DEVELOPING INTEGRATED NUTRIENT MANAGEMENT

To meet the challenge of food security for present and future generation and management, to conserve natural resources, and to protect the environment, it is imperative that land use and management takes into consideration both agricultural productivity and its sustainability (Biswas, 1994; Hera, 1996).

The mission of the Joint FAO/IAEA Division is to develop improved technologies for sustainable food security involving nuclear methods. Within the Division, the Soil Fertility, Irrigation and Crop Production has the mandate to increase and sustain soil fertility and crop production through improved integrated nutrient and water management in cropping/farming systems, with minimum adverse effect on the environment.

As it has been previously reported, the Section has implemented a series of Co-ordinated Research Programmes, which were largely developed around a particular topic such as rice or corn fertilization, biological nitrogen fixation in grain or pasture legumes or the availability of phosphate fertilizers. The selected topics were considered to be relevant to address specific soil/water problems of sufficient importance to food production in developing countries (Hardarson, 1994; Zapata and Hera, 1995).

Whereas in the past, such compartmentalization of the research topics was appropriate and even desirable, future soil fertility research for sustainable food security requires a more holistic approach on integrated nutrient management (INM). The traditional fertilizer-based dose-effect research is being replaced by the research on INM (Smaling and Fresco, 1993). In a similar way, the focus of the research supported by the Section will shift from the specific topic at the crop level to the integration of nutrient and water management at the cropping/farming system.

This INM approach basically implies the judicious management of nutrient inputs, nutrient outputs, and flows within the farming system. Farming systems can include different components and adequate models would need to be developed by identifying the relevant nutrient pools and flows, and the key processes involved (Stoorvogel et al., 1993). Estimating and monitoring nutrient flows and quantifying the impact of INM systems on soil fertility, and hence on agricultural production and its sustainability will be a high priority research task. Isotope techniques will play a key role for measuring and monitoring nutrient flows in the INM systems under study (Zapata and Hera, 1995).

Another application will be the development and validation of appropriate simulation models by critically assessing the relative importance of the chemical, physical and biological factors affecting nutrient availability to plants, for instance soil P bioavailable and nitrogen losses such as ammonia volatilization, denitrification and nitrate leaching.

Therefore, future activities supported by the Section through the Research Contract and Technical Co-operation Programmes will be developed within the overall framework of integrated nutrient and water management at the cropping /farming system level.

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